in coöperation with LeAF

May 2003

Rowafil waterrecycling

Rowafil waterrecycling manual

we care for water

Introduction to this manual

In the many years now that Rowafil Waterrecycling has been constructing, selling and maintaining the Dynamic systems, we often encountered clients and distributors having lots of questions about water quality parameters, microbiological and chemical questions, and how it all comes together in our system.

In order to give everybody some more background information about the biological way of waterrecycling for vehicle washing, we decided to write this “manual” for the Rowafil Dynamic series. It is not a technical manual, but it gives insight in the components, processes and requirements of our Rowafil Dynamic system. You can find more information about Rowafil on the internet: www.rowafil.com

This manual has been written in coöperation with Lettinga Associates Foundation, an independent private firm of world-renowed scientists with many years of experience in their field. Several employees of the sub-department of Environmental Technology and of the Laboratory of Microbiology at the Wageningen University, Netherlands, established the foundation in 1997. It is based in Wageningen and keeps close ties with the university. You can find more about them on the internet as well: www.ftns.wau.nl/lettinga-associates

The manual starts off with a short description of water treatment, followed by an introduction to microbiology and some of it’s processes and influential factors. You can take a closer look at specific compounds found in vehicle washing situations, as well as some water quality parameters. Then of course there is the detailed information about the Rowafil Dynamic systems and it’s components. The manual ends with possible problems and how to avoid them, as well as bringing some safety aspects to your attention.
There’s a reading list if you would like to find out even more about (biological) water treatment, as well as a explanatory word list in various languages to help you out if some words are not understood.

We hope that you, as the reader of this manual, will appreciate our efforts in trying to teach you a little bit more about the Rowafil Dynamic systems. May it be a useful guide to you in understanding more about biological waterrecycling.

With kind regards,

The Rowafil team.

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1. Carwash water recycling

Clean water is getting scarce, and every effort has to be made to preserve the water we still have left. Because of the scarcity, water will also become increasingly expensive. Next to making sure that in the future our children and grandchildren will have clean water, saving water means saving money today (reduced water consumption and sewer discharge costs). A lot of tap water is used for washing cars. Usually, this water is much cleaner than would be necessary, but we use it because tap water is the only kind that is available.

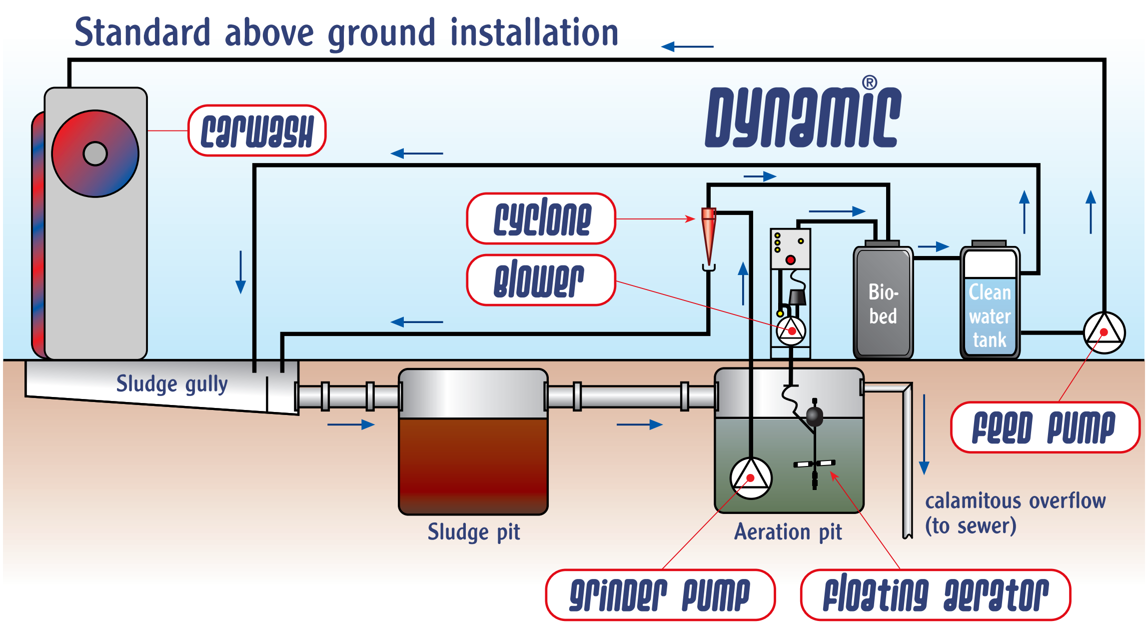
The consumption of freshwater is different for each carwash-type. For instance, a self-service operator will use less water and have higher evaporation and carry-out losses than a tunnel wash. An average water consumption by carwash type is given in the table below:

Carwash type	Litres per vehicle	Gallons per vehicle
In-Bay (roll-over)	250	65
Self-Service	100	25
Conveyor (tunnel wash)	200	53
Truck wash	800	210

For each carwash type the amount of water varies with variations in the chosen wash program: is chassis wash included, a final rinse, etc. For large vehicles like trucks and buses, water consumption is of course much higher. Replacing freshwater with reclaim water can lead to savings of up to 90% in freshwater consumption. A 100% closed loop system will never be possible, as water is always lost because of evaporation and carry-out. On average the water loss will be 10-20%. Next to money saving and benefits to the environment, water restrictions can be a good reason to recycle your water. In some countries, especially during hot summers, carwashes can be forced to close or work under restrictions due to a lack of water. With a recycling system, carwashing can continue even under these restrictions.

1.1 Rowafil system

Rowafil builds water-recycling systems for carwash facilities. The figure below shows a scheme of such a system. Reclaim water is used in the washing and rinsing cycle. To avoid spotting a final rinse could be done with tap water, R.O. (reverse osmosis) water or D.I. (de-ionised) water. Depending on the carwash type, this new water brought into the system with the final rinse, can be sufficient to compensate for water losses due to evaporation and carry out. If this is not the case, from time to time new water will have to be supplied.



1.2 Water treatment

One can say that carwash water is a very specific type of water. Although it changes a lot in composition between different carwash sites and between seasons, in general the compounds present in the wash water are the same. However, in the carwash industry different types of wash operations are used. Each operation has its own needs and characteristics, and leads to a different water. The most important variations have to do with:

- the amount of water used
- the amount and type of contaminants that have to be cleaned from the vehicle
- the chemicals used in the cleaning processes.

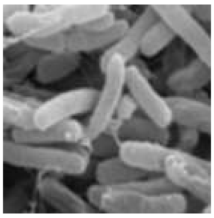
For instance: in-bay automatic carwashes often use friction and/or pressure together with chemicals to achieve a good quality wash. Touch-free automatics (pressure-based) consume a comparable amount of water per car, but as the chemicals do all the work, larger amounts of chemicals are needed to reach the same quality. Next to the detergents (surfactants) and waxes used for washing the cars, the wash water contains oil, road dirt, and other impurities coming from the cars. A bioreactor can be used to purify the wash water. The micro-organisms present in the bioreactor need to be able to remove the mentioned substances (to a certain extent) from the wash water. Chapter 2 gives an introduction on how micro-organisms work and what is involved in letting them grow.

2. Introduction to Microbiology

Microbiology is the science of micro-organisms. Categories of micro-organisms are protozoa, algae, fungi, bacteria and viruses. In a bioreactor such as used by Rowafil, oxygen-using bacteria are the most important organisms. Oxygen is an element that can be present in many forms. When the word "oxygen" is used in this manual, it refers to oxygen as it is present in the air, in form of O_2.

2.1 Bacteria

Bacteria are too small to be seen without a microscope. A bacterium consists of only one cell, with an average size of 2 μm (micrometres) in length and 0.5 μm in diameter. To compare: 1 millimetre is 1000 μm, an average human hair has a diameter of 100 μm. Depending on their shape, they can be longer or shorter. Spherical bacteria are usually shorter, while rod-shaped or spiral-shaped bacteria can be longer.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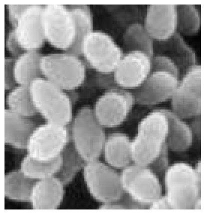
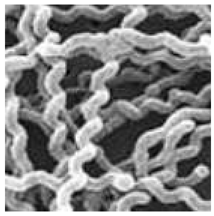

spheres


spirals (1)

(1) Source: CDC/NCID/Rob Weyant

Bacteria are very versatile, and are found literally everywhere on the planet. All species are specialised to live in certain conditions. Aerobic bacteria for instance need oxygen to grow, but anaerobic bacteria use other compounds (see §2.3) and die when they are exposed to oxygen. Most bacteria prefer moderate temperatures, but others grow best at very low or very high temperatures. In the Rowafil bioreactor, many different species of bacteria are present. They all perform certain tasks, removing the pollution using different processes. The most important processes in the bioreactor need oxygen, and that is why a lot of effort is put into providing the reactor with oxygen. However, other processes that occur without oxygen are very useful and can take place in the bioreactor as well. These aerobic (with oxygen) and anaerobic (without oxygen) processes will be explained in the next paragraphs. How it is possible that these processes can occur at the same time will be explained in chapter 5.

2.2 Aerobic Processes

When oxygen is present in a system, microbiologists say that the system has "aerobic" conditions. The Rowafil bioreactor is continuously supplied with oxygen. Therefore, most of the bacteria present in the bioreactor are so-called aerobic bacteria. All bacteria, like all living organisms, need food to grow. In microbiology, this food is called substrate. As a substrate, bacteria can use the same things that humans use: carbohydrates, proteins and fats. And just like humans, aerobic bacteria need oxygen to live: oxygen is used to "burn" food to obtain energy. In a sense, they "breathe" oxygen, just like we do. The organic material present in the water will be oxidised by the bacteria. Oxidation is degrading molecules using oxygen.

In chemistry molecules are presented in formula, using letters to indicate atoms, and numbers to indicate the amount of atoms. Carbon is "C", oxygen is "O" and hydrogen is "H". Organic compounds are made up for the largest part of these three elements. An example of such a formula: $C_4H_8O_2$. A complete oxidation will result in the formation of carbon dioxide and water. In fact it is a balance in which the number of different atoms before and after the arrow is the same. In this example 4 C-atoms, 8 H-atoms and 8 O-atoms:

$$C_4H_8O_2 \quad + \quad 5\,O_2 \quad \longrightarrow \quad \begin{matrix} 4\,CO_2 \\ 4\,H_2O \end{matrix} \qquad \begin{matrix} \text{[2 O-atoms coupled to 1 C-atom]} \\ \text{[1 O-atom coupled to 2 H-atoms]} \end{matrix}$$

This is the principle of biological treatment of water containing organic compounds, one could say the organic impurities disappear. When converting organic material to CO_2 (carbon dioxide) and H_2O (water), the bacteria obtain energy and building materials. They use the energy and the materials to grow. For bacteria, growing means making new bacteria. CO_2 can go out of the water as a gas, H_2O is just water. Next to carbon, hydrogen and oxygen, other atoms can be present in organic matter. These can also be oxidised by the bacteria. For instance, when oxygen is coupled to nitrogen (N), phosphorus (P) and sulphur (S), the following compounds will be formed: nitrate (NO_3), phosphate (PO_4) and sulphate (SO_4).

2.3 Anaerobic processes*

In places where no oxygen is present, anaerobic bacteria start to grow. These bacteria cannot live when oxygen is present. Instead of oxygen, they use other compounds like for instance nitrate, sulphate, dissolved metals or organic compounds. Anaerobic bacteria are capable of breaking down many compounds that aerobic bacteria can not break down. For some compounds this can mean that the anaerobic bacteria only perform a few first difficult steps. What is left over from the anaerobic breakdown, will be eliminated further by aerobic processes. A complete anaerobic breakdown would consist of the following parts:

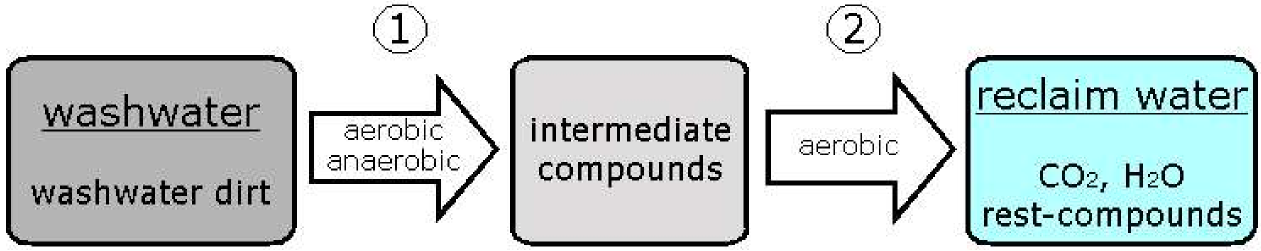
- Large compounds are decomposed into smaller compounds
- Compounds from step one are made even smaller. The main products are acetate (the acid in vinegar), carbon dioxide and hydrogen gas.
- Acetate, and H_2 are transformed into the end products; methane (CH_4) and CO_2.

In the Rowafil system this sequence of processes will probably not proceed completely. Products from the anaerobic processes will be used by aerobic bacteria. They grow faster than the anaerobic bacteria and will take advantage of the products of their colleagues, as soon as those products are available for them.

* Note: Many people automatically link anaerobic processes to problems with bad smelling reclaim water. This fear is not always justified. In paragraphs 5.4 and 6.4 will be explained why the Dynamic system only has the advantage of anaerobic bacteria helping to purify the wash water, but no problems of malodour.

2.4 Working together (synergy)

In practice, aerobic and anaerobic bacteria will work together to convert the dirty wash water in reclaim water. Many compounds can be degraded only aerobically, but there are also compounds that can only be degraded in absence of oxygen. Anaerobic/Aerobic is only a very rough division of bacteria in two groups. These two big groups are made up out of a lot of different species of bacteria, and each species will do what it is best at.



The picture above is a schematic representation of the processes occurring in the bioreactor. In the first step both anaerobic and aerobic bacteria will attack the dirt present in the wash water, breaking large compounds into smaller ones, or difficult ones into easier ones. In addition, the easiest compounds will be completely degraded. Intermediate compounds produced in step 1 will be degraded completely in step 2, by aerobic bacteria. Ideally, only CO_2 and H_2O would be formed, but in practice there will always stay some small rest-compounds in the water. This is normal for any biological system and in normal situations this has no negative effects on the quality of the reclaim water.

2.5 Nutrients

In addition to substrate, nutrients are essential for bacteria. Without these elements, certain components in the bacterial cell do not function. Some nutrients, called “macro-nutrients” are needed in quite large concentrations. Others, mainly metals, are needed in small concentrations and are called “micro-nutrients”.

2.5.1 Macro-nutrients
The most important nutrients are nitrogen, phosphorus and sulphur. Bacteria obtain these nutrients from the medium in which they are living. In this case, the medium is carwash water. Small molecules containing nutrients are taken up by the bacteria. Some examples: ammonia for nitrogen, phosphate for phosphorus and sulphate for sulphur. Not every medium contains enough nutrients to support growth of bacteria, and not all bacteria need the same quantities to perform well. If a medium does not contain sufficient amounts of nutrients for the bacteria that are needed to grow, they have to be added. In too large concentrations however, some nutrients can be toxic to bacteria.

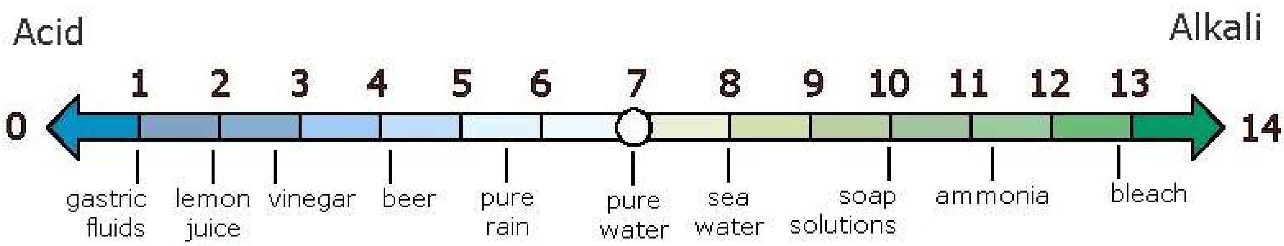
2.5.2 Micro-nutrients
Next to macro-nutrients, bacteria need small amounts of other nutrients such as metals. Just like macro-nutrients, these are taken up from the medium. Potassium, magnesium, iron and calcium are examples of metals that are essential. Although the needed amount is small, it can happen that the concentration of these metals in a medium is not high enough for bacteria. Some other metals are needed in such small quantities, that the amounts present in plain tap water are sufficient. Examples of these so-called trace metals are copper, cobalt and zinc. As the concentrations needed by the bacteria are very low, it is very easy to fulfil this need. It is possible that in some cases the amount of metals will be too high. Very high concentrations will be toxic and inhibit the bacteria.

2.6 Environmental Factors
Environmental factors are very important for all living things, including a microbiological system like the bioreactor used by Rowafil. The bacteria have to perform a specific task, in this case cleaning wash water. By choosing the right conditions, the right bacteria for the task are stimulated to grow.

2.6.1 Temperature
The highest and the lowest temperature that support growth for a bacterium are usually around 30-40ºC apart. Most of the bacteria in the bioreactor will be able to grow between 10ºC and 40ºC (between 50ºF and 104ºF). Between the minimum and the maximum, there is an optimum temperature at which growth is best. Each species has its own optimum. A low temperature merely makes the bacteria less active, but a too high a temperature can easily kill them.

2.6.2 Oxygen concentration
As explained in § 2.2 and § 2.3 the oxygen concentration is very important to control the processes taking place in the bioreactor. For standard aerobic wastewater treatment plants an oxygen concentration of around 2 mg/l is maintained in the system. At that concentration the aerobic bacteria have oxygen to live and the transfer of oxygen from the air-bubbles to the water is very efficient. This value of 2 mg/l can be seen as the minimum concentration. In the Rowafil system, the oxygen concentration is kept at a higher level to assure that in the entire reactor the aerobic bacteria will have more than enough oxygen.

2.6.3 Acidity and alkalinity (pH)
The pH is a measure for the relative acidity or alkalinity. Its scale ranges from 0 to 14. A pH of 7 is considered to be neutral. Water with a pH of less than 7 is acidic; water with a pH greater than 7 is alkaline. Some examples of pH values: vinegar has a pH of almost 3, pure water has a pH of 7 and household ammonia has a pH of 11.



Just as for temperature, every bacterial species has also its pH minimum, optimum and maximum. Most bacteria grow best at a pH between 6 and 8, with an optimum slightly above 7. Below pH=4 or above pH=9 many species will die. Bacteria take up compounds present in the medium that surrounds them. After breakdown of these compounds, the bacteria release degradation products to the medium. In this way they influence the pH of their environment, and their own and other bacteria's growth.

2.6.4 Inhibition

When the bacteria are inhibited, this means that they can not function optimally. If the inhibition is strong enough, it can even kill the bacteria. A slight inhibition will allow the bacteria to keep on doing their work, but not so efficient as when the conditions are optimal for the bacteria. "Optimum conditions" involve temperature, pH, oxygen concentration, presence of suitable substrates, absence of toxic chemicals, etc. So all of the factors discussed in this chapter play a role, as well as everything else that enters the water. Including the chemicals used in the carwash.

Temperature
The temperature in the carwash will usually not be a problem, although many bacteria have optimum temperatures (usually around 30ºC / 86ºF) above those found in a carwash. Natural selection and adaptation make sure that reactor will work well at lower temperatures, so in most cases heating the water would be a waste of energy and involve too high costs. However, to keep a good reactor performance the temperature should stay above 10ºC (50ºF). This means that in very cold countries heating of the water must be considered, in order to obtain this minimal water temperature.

Oxygen
Aerobic bacteria will function well at an oxygen concentration of 2 mg/l or higher. A lower concentration can cause the system to work less effectively. When the concentration drops to 0 mg/l only anaerobic bacteria will be active, and this can cause the presence of malodorous compounds in the reclaim water. Therefore a good aeration is very important.

Acidity/Alkalinity
Bacteria are quite sensitive to changes in pH. However, when the pH changes slowly and stays between pH=6 and pH=9, most bacteria can tolerate this quite well. Drastic pH changes do more damage, because the bacteria do not have the time to adapt to the change. The safest way is to make sure that the reactor always has a pH near optimal, just above 7.

Carwash related inhibition
The factors mentioned above play a role in all wastewater treatment systems. A carwash site is a very specific environment: Many products used in carwashing contain chemicals that can inhibit bacteria, but also the substances washed away from the cars can affect the bioreactor. Additionally, accidents or deliberate dumping of chemicals (battery acid for example) can cause inhibition of the bacteria. In chapter 3 the potential inhibiting effects of carwash products are discussed more extensively.

3. Carwash specific compounds: biodegradation and inhibition

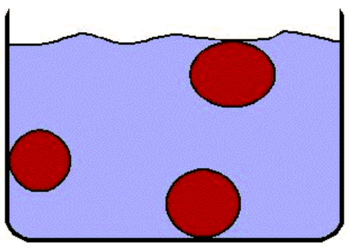
Carwash water is a very specific wastewater. Typical contaminants are detergents (surfactants), waxes and oil. Each component has different characteristics for degradation. Some can even be inhibitory to bacteria if they occur in too high a concentration. But inhibition does not mean that degradation is not possible. Ideally, a compound is not inhibitory, and easily and completely biodegradable. In the worst case, a compound is inhibitory, but not biodegradable at all.

	Degradable?	Inhibitory?	Effect
Best case	Yes	No	No effect, compound will be degraded.
↓	Yes	Yes	Compound will ultimately be degraded but biomass can be affected negatively. Also degradation of other compounds might be affected
	No	No	No degradation, the compound will accumulate in the system and might affect the system when the concentration gets very high.
Worst case	No	Yes	No degradation, and a negative effect on the biomass. The compound will accumulate and can cause complete failure of the system.

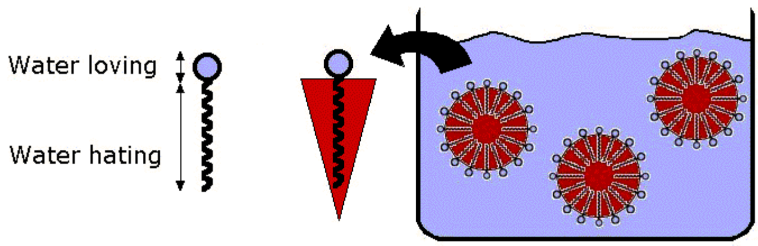
Looking at the table, the wisest thing to do is to select only those carwash products that contain ingredients that are degradable but not inhibitory. In practice however, some compounds are needed for special properties that do not comply with that requirement. For example some compounds present in waxes (see also § 3.2). All ingredients in carwash products have their own characteristics when it comes to biodegradation.

3.1 Detergents

Detergents are surface-active compounds, also called "surfactants". When added to a liquid surfactants change the properties of that liquid at a surface or interface. Surfactants are structures consisting of two parts: a hydrophilic ("water loving") part and a hydrophobic ("water hating") part. The hydrophilic side is water soluble, and the hydrophobic part is not soluble in water. The figure below explains how detergents work.



Greasy dirt, does not dissolve in water: difficult to remove from a surface using just water



The water hating part wants to be in the dirt, the water loving part on the outside. This makes that the dirt "looks" like water and can dissolve in water. Now it can be removed easily.

Detergents are normally divided in four groups, depending on the form of the hydrophilic part. The main classes of detergents are anionic, cationic, non-ionic and amphoteric.

Anionic: A negatively charged molecule.

Cationic: A positively charged molecule. Of the cationic surfactants especially the quaternary ammonium compounds are used in commercial products.

Non-ionic: The molecule is not charged. Non-ionic surfactants have both hydrophobic and hydrophilic properties.

Amphoteric: These can act as cationic or anionic detergents, depending on the pH of the water.

Anionic and non-ionic surfactants are most widely used. Cationic surfactants are less effective detergents, but they are present in waxes because they have a very good ability to stick on to surfaces (vehicles have a negatively charged surface). Cationic compounds will be discussed in paragraph 3.2, Waxes.

Biodegradation
Most of the non-ionic, anionic and amphoteric surfactants have a high biodegradability, and will normally be eliminated from the wash water without difficulties. World-wide, legislation is getting stricter on the use of non-biodegradable chemicals, because of the damage they do to the environment. Therefore also in carwashing more and more of the products pose no problems for the bacteria in a treatment system. Within the range of available detergents, there are always differences in biodegradability.

Inhibition
When concentrations are too high, bacteria can be inhibited even by highly biodegradable compounds. Surfactants change the properties of surfaces, and can therefore change the properties of surface of bacteria. The “skin” of bacteria is a quite delicate membrane. When surfactants change its properties too much, it can be permanently damaged. The large amounts of water in the pits will most of the time prevent surfactant concentrations to get too high.

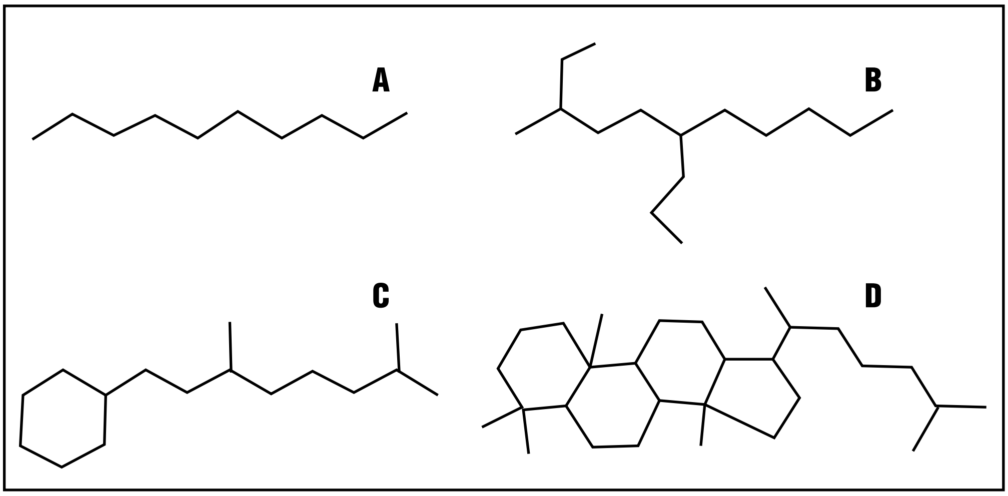
3.2 Waxes
Waxes are used to put a protective layer on the car. In an automated carwash, waxes are sprayed on using water. Therefore waxes need special properties to make sure they do not wash away, but stick onto the car. Examples of possible ingredients of waxes are carnauba wax, mineral seal oil and silicones.

Biodegradation
Waxes might be the most difficult materials to degrade in a bioreactor. They are designed to stick to the cars to form a protective layer, and the properties that are required to achieve this are at the same time properties that make them very difficult for bacteria to degrade. Silicones for example are hardly degradable at all, and will accumulate in the system. As far as is known, they are also not toxic. In that respect, for the bacteria the presence of silicones will not be a problem. However, the quality of the reclaim water may be affected after some time. An example is the adverse effect on the appearance of the water: a high amount of silicones can make it look cloudy.

Inhibition
Next to inert ingredients like silicones, waxes can contain compounds that are inhibitory to bacteria, like for instance quaternary ammonium salts or “quats”. In addition to being toxic, many quats are very difficult to degrade. This may lead to accumulation in the reclaim system and inhibition of the bacteria. In higher concentrations quats will lower the treatment efficiency. Some of them are not so difficult to degrade; there is a large variety of quats, each with its own degree of biodegradability and toxicity. Quats have excellent water repelling qualities and stick very well to vehicles. Therefore they are used in a lot of wax products, and still there are almost no alternatives available. The development of easily biodegradable alternatives will only be a matter of time. Promising chemicals that are already being used in various household applications are the so-called “esterquats”.

3.3 Oil and grease
As you expect from a carwash, the wash water will contain oily substances. These can come from any of the petroleum products on the vehicle's surface, or from leakage from the vehicle or any lubricants in equipment. The exact composition of these substances is unknown, as most oily products are mixtures of many different compounds.

Biodegradation
Due to the large variety in oil and grease compounds that enter the water, it is difficult to predict the ultimate biodegradation of the total oil and grease content of the water. In general one can say that biodegradability increases with decreasing size and complexity of the molecules. Straight chains (A) will be easier to degrade than chains with branches (B), which will be easier to degrade than structures with rings (C). Structures with multiple rings (D) are most difficult to degrade.



The low water solubility of many oily compounds makes it hard for bacteria to attack them. As bacteria need to be surrounded by water, they need a compound to be dissolved in water before they can reach it. In this sense, the first difficulty in degradation is the availability of the compounds for the bacteria. However, carwash water contains a lot of surfactants, and these may help to increase the amount of available oily compounds. Surfactants and solvents can improve the solubility of otherwise poorly soluble compounds. Another difficulty is the size and stability of some of the compounds. The ring structures for instance are very strong, and the bacteria first have to break the rings to be able to degrade the compound.

Inhibition
Many compounds that belong to the “oil and grease” group can be inhibiting towards bacteria, but the concentrations present in a carwash are quite low and normally problems are not expected. Because of the sludge pit and the aeration pit, dilution takes place. Very large amounts, for instance due to dumping of motor oil, will certainly have a (temporary) negative effect on the system. The recuperation time of the bioreactor depends on the amount of oil that entered the system.

3.4 Road dirt
Biodegradation
Most road dirt will be non-degradable. Examples are sand, dust and road-salt. Organic materials like pollen and plant matter can be partly degradable. Road dirt is not expected to be toxic, but it mostly consists of solid material and can therefore cause problems in a reclaim system that does not take measures for solids removal. Examples are clogging of pipes or clogging of the aeration system. In the Rowafil system, solids are taken care of at two points: the sludge pit and the hydrocyclone. In the sludge pit, heavier solid materials like coarse sand will settle and remain there. Lighter materials will flow with the water to the aeration pit. From the aeration pit, water is pumped up by a grinder pump, making big solid materials smaller. Before entering the bioreactor, the water and small solid particles pass a hydrocyclone, in which the solid particles are separated from the water.

Inhibition
It is not likely that the bacteria will be inhibited by road dirt.

3.5 Salt

Salt is not necessarily present in high concentrations in all carwashes, although carwash chemicals contain salts like sodium metasilicate, sodium hydroxide, sodium chloride and others. An obvious source of larger amounts, is the use of salt to keep roads free of ice. In higher concentrations, salt can be a problem. It causes spotting of cars, and this will occur quickly with rising salt levels. When the concentration gets too high, part of the reclaim water will have to be replaced with new water. In case of a final rinse with R.O.- or D.I.-water the salt level can be allowed to be higher, because salt that remained on the cars will be rinsed off in this last step anyway. A reclaim system has a water balance of new water coming into the system (e.g. last rinse with R.O. water), and “old” reclaim water leaving it (e.g. carry-out by vehicles, overflow of excess water). In this way normally the salt concentration does not rise too fast.

Biodegradation
Salt is not biodegradable, and will accumulate in a system where it regularly enters the water.

Inhibition
The bacteria that do the work in the Rowafil recycling system can tolerate a certain amount of salt, but usually this amount is not very big. In combination with the risk for spotting, this makes the salt concentration something to pay attention to.

3.6 Heavy metals

Cars are made of metal, but the heavy metal concentration in the wash water is almost never too high. Only zinc and copper sometimes exceed the concentration limits set in discharge norms, usually when copper or galvanised piping is used in the carwash equipment. Other sources of zinc are paints and rubber brake pads.

Biodegradation
Metals as such are not biodegradable, but they can be taken up by bacteria. As mentioned in chapter 2, low concentrations of metals are necessary for the wellbeing of bacteria.

Inhibition
When the concentrations are too high, bacteria can be inhibited. However, the risk of having such high concentrations in the wash water is minimal.

3.7 Battery acid and other chemical spills

If one of the customers decides to use the carwash as a chemical waste deposit, this can seriously upset the system. Most at risk in this case are the self-serve washes, where nearly anything can be dumped in a pit. Water treatment systems where the bacteria are attached to a carrier material, are generally more resistant to toxic shocks than systems where the bacteria are free in the water. Nevertheless, a big shock load of extremely toxic material like battery acid will be very harmful to the treatment system. In the worst case, lots of bacteria will die and the system will have to be restarted. Flushing the system with clean water and allowing a recuperation period might do the trick when not all the biomass has died.

4. Measuring water quality

In the field of wastewater treatment, water quality is determined by measuring various parameters. The most important ones for a carwash reclaim system will be explained in this chapter.

4.1 Amount of pollution

4.1.1 Chemical Oxygen Demand (COD)

The COD is a widely used parameter in wastewater treatment. A very strong chemical oxidant is used to determine in a sample of water the amount of substances that can be oxidised. This determination is carried out in a laboratory, under controlled conditions. A strong acid is added to the sample, together with the oxidant. This mixture is kept at 150ºC (302ºF) for two hours,

left to cool down and then analysed. COD gives an indication of the total amount of organic contamination present in the water. Because for the COD determination a strong chemical is used, the resulting value does not say if the pollution present in the wastewater is biodegradable. Usually it is expressed in milligrams of oxygen per litre (mg/l). After purification the COD of the water should be very low.

4.1.2 Biochemical Oxygen Demand (BOD)

Another commonly used measurement is the biochemical oxygen demand. Contrary to the COD, the BOD is an indication of the total amount of pollution that can be oxidised by aerobic bacteria. Consequently, the BOD value is never equal to the COD value, but always lower. The most commonly used BOD method is called “five day BOD” or BOD_5. In the laboratory, a water sample is seeded with a small amount of bacteria. The bottle is made airtight and the amount of oxygen present in the bottle is measured regularly for a period of five days. When a sample contains biodegradable material, the bacteria are able to use it to grow, and will start using oxygen to degrade it. The amount of oxygen consumed by the bacteria is a measure for the amount of biodegradable material present in the water sample.

Because the bacteria will never be able to oxidise the same amount as the chemical oxidant, the BOD is always lower than the COD. Like the COD, also BOD is expressed in mg of oxygen per litre. Eventually the BOD disappears completely, indicating that all biodegradable material has been removed. Not all biodegradable material can be oxidised in a short time, there will always be a rest concentration of slowly biodegradable compounds. Therefore, in a system like the Dynamic that is continuously provided with new substrate, the BOD will never be removed completely.

4.2 Dissolved Oxygen (DO)

Because the bioreactor is a biological system with mainly aerobic bacteria, the concentration of oxygen dissolved in the water is very important. The amount of oxygen is measured with a sensor, and usually expressed in mg/l or % saturation. For biological aerobic water treatment systems, a concentration of 2 mg/l is the minimum. Dissolved oxygen is measured using a “DO-sensor”, usually capable of showing the DO in both mg/l and %.

The maximum amount of oxygen that can dissolve in water depends on the temperature, and to a lesser extend on barometric pressure and salinity. In warmer water, less oxygen can dissolve. An indication: Water of 15ºC (59ºF) with a low salt concentration and at sea level will have a maximum concentration of 10 mg/l. If 2 mg/l is dissolved, than this is 20% of the maximum. In the same water at 20ºC (68ºF), the maximum concentration is only 9 mg/l. Here, if 2 mg/l is dissolved, then this is 22% of the maximum.

4.3 pH
Acidity (or alkalinity) of water is expressed as pH (see § 2.5.3). The pH of a sample of water is a measure of the concentration of hydrogen ions. At a higher pH, there are fewer hydrogen ions then at a low pH. The concentration of hydrogen ions is measured with a sensor when very precise measurements are required. To get an indication if the pH value is in the right range, “pH paper” can also be used. This paper gives a different colour for every pH. The pH is calculated in such a way, that a change of one pH unit reflects a tenfold change in the concentrations of the hydrogen ion. For example, there are 10 times as many hydrogen ions available at a pH of 6 than at a pH of 7. Ideally, the pH in the bioreactor should be just above 7.

4.4 Salt
The concentration of salt is very important, because of spotting of cars and inhibition of the bacteria. The amount of salt can be measured in two different ways. Depending on the country the preference for one of the two methods can change.

4.4.1 Conductivity
Conductivity is the ability of the water to conduct an electrical current. It is directly related to the amount of salt dissolved in the water, because the dissolved salt transports the current through the water. Conductivity is measured with a special sensor that has two metal electrodes that are exactly 1.0 cm apart. A constant voltage is applied to the electrodes, making an electrical current flow through the water: the more dissolved salt, the higher the electrical current. Conductivity is expressed in microSiemens per centimetre (μS/cm).

4.4.2 Total Dissolved Solids (TDS)
"Dissolved solids" seems contradictory, but when you evaporate a water sample solids will be left. This residue contains any minerals, salts and metals that were dissolved in the water. The TDS concentration is determined in a laboratory. A water sample with a known volume is filtered using a filter that retains all non-dissolved things present in the water. The filtered water is then put into a ceramic dish with a known weight, and placed at a temperature of 105ºC (221ºF). When the sample has dried, the temperature is raised to 180ºC (356ºF) for one hour to make sure that all the water evaporates. The weight of the dish with the dried sample, minus the weight of the empty dish, gives the weight of the dissolved solids present in the original water sample. With this weight and the volume of the water sample the amount of TDS is calculated in mg/l.

4.5 Suspended Solids (SS)
The amount of suspended solids is an important factor in the clarity of the water. Solid particles “floating around” in the water make it look dirty. An example of solid material that can be present in the treated water can be biomass that accidentally came out of the bioreactor, but also very fine clay particles smaller than 5 μm that passed the cyclones. Suspended solids are measured using a pre-weighed filter similar to the one used for TDS determination. A known volume of a water sample is filtered, and then the filter is dried. With the weight of the solid material on the filter and the sample volume, the SS concentration can be calculated. Normally SS is expressed in mg/l.

5. A closer look at the Rowafil Dynamic system

In the steps before the bioreactor, solid material is removed from the wash water. The water entering the bioreactor contains only dissolved substances and very small solid particles (smaller than 5 μm). Bacteria living in the bioreactor remove suspended solids and dissolved organic pollution by entrapment and biodegradation.

5.1 Sludge pit

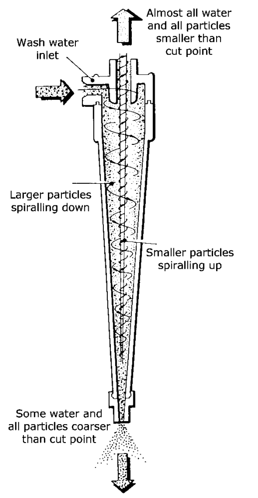
Solid materials like sand, that did not settle yet in the sludge gully, will settle in the sludge pit. The time that the water stays in the pit determines if only heavier things like sand can settle, or also lighter materials like clay for instance. Part of the material that settles in the sludge pit is biodegradable. In any sludge pit bacteria are present, and some degradation of the settled materials will take place. It can be expected that when a Dynamic system is installed, this degradation of organic matter in the sludge pit will be stimulated. Small flocs of bacteria that can grow in the aeration pit (§5.2) are taken out of the water by hydrocyclones (§5.3) and led to the sludge pit, increasing the amount of active bacteria. Reclaim water will contain rests of dissolved nutrients (§5.5) that may be used by the bacteria in the sludge pit. A better degradation of the material in the sludge pit means it will take a longer time to fill up with sludge, therefore reducing the maintenance/cleaning intervals.

5.2 Aeration pit

From the sedimentation pit the water flows to the aeration tank. Aeration is the process of blowing air in the water, to transfer the oxygen from the air to the water. In the aeration tank, air is blown into the water using a floating aerator with special membranes. Doing this, the water already contains oxygen when entering the bioreactor. An additional benefit is the mixing of the water. Aeration causes a lot of movement in the water. New washing water entering the aeration tank will be blended with the water already present in the tank, diluting possible inhibitory compounds. In addition, due to the aeration the pit will start to function as a sort of ‘pre-bioreactor’. A layer of bacteria similar to the ones in the bioreactor will form on the wall of the pit and on the aeration system. These bacteria will already make a small start with the purification of the water, although compared to the bioreactor this will not be much.

5.3 Cyclones

From the aeration tank the water is pumped with a grinder pump to the hydrocyclone. The grinder pump makes sure that the particles that enter the cyclone are smaller than 1 mm, to prevent clogging. Water enters the cyclone at the top, and the special shape of the cyclone forces the water make a spiral movement. Hydrocyclones can be designed to separate particles of a certain size (“cut point”). In this case, particles smaller than 5 μm and most of the water are forced to spiral upwards, and particles bigger than 5 μm and a small amount of water are forced to spiral downwards. The flow from the top is led to the bioreactor, free from large solid particles. The bottom flow containing the solids is led to the sedimentation pit. Hydrocyclones have a maximum throughput flow. In the case of the hydrocyclones used in the Rowafil system, this is 2 m^3/hour (528 gallon/h).



5.4 Aerated Bioreactor

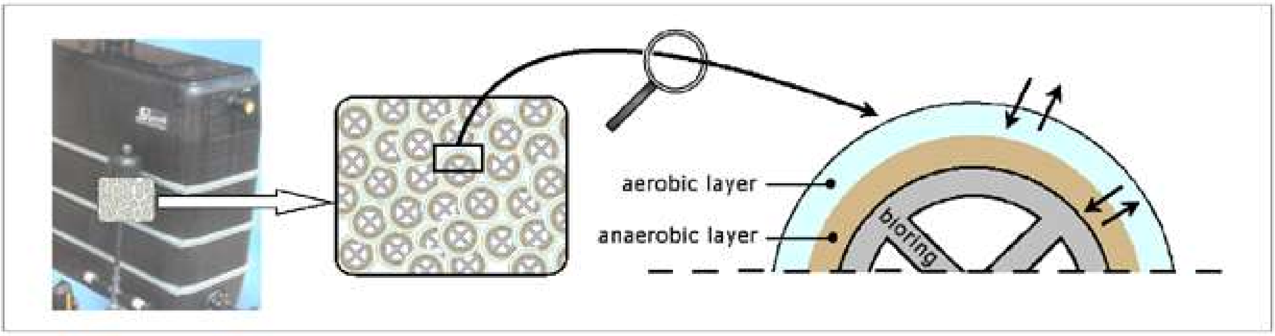
Air is pumped continuously into the bioreactor to ensure a good oxygen supply during purification. When the bacteria that use oxygen do not receive the amount they need, the bioreactor will not perform well. The input of air is also very important for the mixing in the reactor. The system has to be mixed very well to make sure that all contamination comes in contact with the bacteria. The only other mixing system applied in the reactor is the upward water flow.

5.4.1 Biorings

To get a good removal of the compounds present in the wash water, the amount of bacteria in the bioreactor is very important. If the bacteria would be floating freely in the water, they would enter and leave the bioreactor with the water. Because of the aeration, probably some purification would take place, but not sufficient to produce water of reuse quality. Therefore, the bioreactor is filled with so-called 'biorings'. When the operating conditions are right, bacteria will start to grow in layers on the biorings and cover them completely. These film-forming bacteria excrete a glue-like substance that anchors them to the bioring. In this way, they can not leave the reactor. Because they are very close together they are capable of working very efficiently: the short distances make transport of substrates and nutrients between the bacteria very easy. Different types of bacteria will be present in different places in the layers, according to where the conditions are better for growth.

5.4.2 Biofilm (the layer of bacteria on the biorings)

Because the bacteria grow in layers, oxygen can only penetrate partly into the biofilm. The aerobic bacteria in the outer layer take away all the oxygen and, consequently, anaerobic bacteria can develop in the inner layers. In this way, in the reactor anaerobic and aerobic processes can take place at the same time. Below a schematic representation of a covered bioring is given. Oxygen rich and oxygen poor zones are illustrated (blue and brown), as well as the transport of compounds occurring in the biofilm (arrows).



Transport of compounds takes place in various directions:

- water to aerobic zone: all kinds of compounds
- aerobic zone to anaerobic zone: partly degraded compounds and aerobically non-degradable compounds
- anaerobic zone to aerobic zone: degradation products
- aerobic zone to water: ultimate aerobic degradation products

5.5 Addition of nutrients and adapted bacteria

Carwash water does not always contain sufficient nutrients for bacteria. To assure that the bioreactor functions well, it is very important that the bacteria receive the right amount of nutrients. Therefore SR16, a special mix of nutrients, is added continuously to the system. SR16 also contains bacteria an yeasts that are specially adapted to degrading detergents and oils. Because of the right mix of bacteria and nutrients, it is very useful as a help for a fast start-up, and to shorten the recuperation time in the case of accidents like dumping of inhibiting materials. All ingredients of SR16 are present on the GRAS list, the "Generally Regarded As Safe" lists made by the American Food and Drug Association.

5.6 Clean water tank

The purified water (= reclaim water) flows to the clean water storage tank. From there the water is taken when cars are being washed. When the clean water tank gets too full, the excess water is led back to the sludge pit.

6. Safety aspects and possible problems

6.1 Start-up

The start-up of the system is a critical phase: the reactor is filled with clean new biorings, but the wash water coming in is of the same constitution as in a system that is already fully functioning. Any biological treatment system has a start-up period, in which the bacteria have to grow and adapt to the conditions. In the Dynamic, bacteria and nutrients (SR16) are added to ensure a good and fast start-up. Bacteria will attach to the biorings in the reactor, and start degrading first the easy to degrade compounds. Then they will begin to grow on the rings and to adapt to the characteristics of the wash water. While the rings get covered by bacteria, the efficiency of the treatment system will increase until it reaches its maximum.

6.2 The choice of carwash products

As explained in chapter 3, the compounds that enter the water determine whether the wash water can be purified easily or not. Questions to ask when deciding about using a certain product: are the ingredients biodegradable? are the ingredients inhibitive to bacteria? Rowafil has experience with various brands of carwash products, although it is not yet known for all brands how they will behave in the Dynamic. Rowafil can always advise in this matter. Providing Rowafil with the chemical's Material Safety Data Sheets (MSD-sheets) is most of the time sufficient to detect any possible harmfull compounds in the product.
Rowafil also sells it's own brand of chemical. These chemicals are well selected and especially suitable for use in a vehicle wash with a Dynamic biological recycling system.

6.3 Behaviour of the system when no cars are being washed

When the carwash does not operate for a short time, for instance in the night or during weekends, the Rowafil reclaim system keeps on working. Water will be continuously pumped through the entire system, and when the clean water tank is full an overflow will lead excess water to the sedimentation pit. The bacteria in the bioreactor will have a reduced food supply, but on the other hand the pause gives them time to recuperate from possible inhibitive compounds that entered the water during the operation of the carwash. It also forces them to work on the difficult to degrade compounds in the water.

Long periods without operation of the carwash might cause problems for the bioreactor, because at some moment the bacteria will run out of compounds they can use. Just like humans, most bacteria need a certain minimum amount of food to survive. Lack of food for a long time can cause some bacteria to die. Others will survive, passing to some kind of a resting ("dorment") state. As soon as the carwash is working again, these bacteria will "wake up" and continue to live. The efficiency of the reactor will be lower than before the period that the carwash was not operating, and it will take some time before the system will be recuperated completely.

6.4 Formation of malodorous compounds

The biggest fear of every carwash owner is probably the formation of bad smell. This is usually related to anaerobic conditions occurring in some place in the water system. It was explained in § 2.3, that in the Dynamic-biomass anaerobic bacteria are present. Maybe on first thought this might seem disadvantageous, due to the strong link that exists between anaerobic conditions and problems of malodour. However, these bacteria are helpful in breaking down organic material in the wash water. In case they produce bad-smelling compounds when doing their job, these will be taken away by the aerobic bacteria in the oxygen-containing zone of the biofilm. If aeration is not sufficient, malodorous compounds might pass the aerobic zone without being oxidised, and escape to the water. That is why the Rowafil Dynamic System is continuously aerated: 24 hours a day, 7 days a week. In this way the oxygen concentration will always be high enough.

6.5 Harmful bacteria

As far as is known, the chance of the occurrence of harmful bacteria like Legionella or other pathogens in the reclaim system is minimal. The reclaim water does not make contact with domestic wastewater, which makes contamination with human pathogens unlikely. Legionella can be present in almost any water system, but until now it has not been found at carwashes using the Rowafil reclaim system. Because Legionella prefers warm and stagnant water it is very unlikely that Legionella will pose a problem in a Dynamic waterrecycling system, where temperature is lower and water circulates 24 hours a day.

7. Reading list

Examples of books for further reading:

- Wastewater Engineering – Treatment and Reuse (International Edition)
  Metcalf & Eddy Inc.
  Published by McGraw-Hill Higher Education.

- Brock - Biology of Microorganisms
  M.T. Madigan, J. M. Martinko and J. Parker
  Published by Prentice Hall

- General Microbiology
  H.G. Schlegel
  Published by Cambridge University Press

Word	Explanation	Nederlands	Français	Deutsch	Español	Italiano
Aeration	Passing air through water, causing oxygen from the air to dissolve in the water	Beluchting	Aération	Belüftung	Aireación	Aerazione
Aerobic	When oxygen is present	Zuurstofrijk (aëroob)	Aérobie	Aerob	Aerobio	Aerobico
Aerobic bacteria	Bacteria that need oxygen to live	Aërobe bacteriën	Bactérie aérobie	Aerobe Bakteriën	Bacterias aerobias	Batteri aerobici
Anaerobic	Absence of oxygen	Zuurstofloos (anaëroob)	Anaérobie	Anaerob	Anaerobio	Anaerobio
Anaerobic bacteria	Bacteria that cannot live when oxygen is present	Anaërobe bacteriën	Bactérie anaérobie	Anaerobe Bakteriën	Bacterias anaerobias	Batteri Anaerobi
Atom	the smallest building block of a molecule	Atoom	Atome	Atom	Atomo	Atomo
Biofilm	biomass consisting of layers of different bacteria on biorings	Biofilm	Biofilm	Biofilm	Biofilm	Biofilm
BOD	Biochemical Oxygen Demand	BZV – Biochemisch Zuurstof Verbruik	DBO – Demand Bio-chimique en Oxygène	BSV – Biochemischer Sauerstoff Verbrauch	DBO – Demanda Bioquímica de Oxígeno	DBO – domanda biochimica d'ossigeno
COD	Chemical Oxygen Demand	CZV – Chemisch Zuurstof Verbruik	DCO - Demande Chimique en Oxygène	CSV – Chemischer Sauerstoff Verbrauch	DQO – Demanda Química de Oxígeno	DCO – domanda chimica d'ossigeno
Inhibition	Negative effect on bacteria	Remming	Inhibition	Inhibition	Inhibición	Inibizione
Nutrient	Compounds needed for growth	Nutriënt	Nutriment	Nutrient	Nutriente	Nutriente
Organic compounds	Molecules that are based on carbon	Organische verbindingen	Composés organiques	Organische Stoffe	Compuestos orgánicos	Composto organico
Intermediate compounds	Compounds formed during breakdown of the compounds that were originally present in the wash water. Usually smaller than the original compounds, or just a modification of them	Intermediare (=tussen) producten	Composées intermédiaires	Intermediäre Substanzen	Compuestas intermediarias	Substante intermediare
Oxidise Suppletion water	To degrade using oxygen Tap-, R.O.- or D.I.-water brought into the system	Oxideren Suppletie water	Oxyder Eau nouvelle	Oxidieren Ergänzungswasser	Oxidar Agua nueva	Ossidare Acqua nuova
Reclaim water	Wash water treated for reuse	Recyclewater	Eau recyclée	Recyclingwasser	Agua recuperada	Acqua recuperata
Sensor	Device for measuring concentrations of certain compounds	Sensor	Capteur	Sensor	Sensor	Sensore
Substrate	Food for bacteria	Substraat	Substrat	Substrat	Substrato	Substrato
Trace metals	Essential metals needed by bacteria in minute concentrations	Sporenmetalen	Métaux traces	Spuren-Metalle	Metales traza	Metalli in tracce
Wash water	Water that has been used for washing	Water dat gebruikt is voor het wassen	L'eau qui a été utilisée pour le lavage	Waschwasser vom Waschen	Agua que fue usada para lavar	Acqua usato per lavaggio