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# Schmutzdecke- A Filtration Layer of Slow Sand Filter

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**A B S T R A C T**

Slow sand filtration has been an effective means of treating water for the control of microbiological contaminants. Schmutzdecke is the layer of the microbial community that is responsible for treating the water through the sand bed. As water passes through this biological layer, foreign particles are trapped and essentially eaten by bacteria forms on this layer. Development of Schmutzdecke layer depends on available microbes in raw water, food supply, oxygen supply, residence time, and wetting of sand bed. Generally, 13 types of bacterial community are found in the Schmutzdecke layer, in which Pseudomonas stutzeri bacteria are dominant. Many of the researchers observed that water purification is 90 to 99% after the development of Schmutzdecke or maturity of the filter bed. Head loss of filter is also increased with the volume of water filter, but it can be easily recovered by cleaning of the upper layer of the filter bed.

## Introduction

*Schmutzdecke* is a complex biological layer formed on the surface of a slow sand filter which means “dirty layer” in German. The *Schmutzdecke* is the layer that provides the effective purification of potable water treatment. It is a gelatinous layer or biofilm called the hypogeal layer or *Schmutzdecke*. This sticky film, which is reddish brown in colour, consists of decomposing organic matter, iron, manganese and silica and therefore acts as a fine filter media that contributes to the removal of turbid particles in the raw water. It also doubles up as an initial zone of biological activity and providing some degradation of soluble organics in the raw water, which is useful for reducing tastes, odours and colour. It is formed in the first few weeks of operation and consists of organic matter including bacteria, fungi, protozoa, rotifer and various aquatic insect larvae. It consists of alluvial mud, organic matter, bacteria, diatoms, zooplankton, thread-like algae formed by the excretion of microorganisms. It is the layer of aquatic life that is responsible for purifying the water. As water passes through this biological layer, foreign particles are trapped and essentially eaten by bacteria forms on this layer. As the water slowly passes down through the layers of sand, impurities are left behind, leaving the water between 90% and 99% free from bacteria (Elliott *et al.,* 2008).

*Schmutzdecke* layer formed due to the establishment of a microbial community on the top layers of the fine sand particles. These microbes usually came from the raw water and establish a community within a matter of a few days. The sand bed and slow filtration rate help to the establishment of this microbial community. The majority of the microbial community are predatory bacteria that feed on water-borne microbes passing through the filter. The microbial population is limited by the amount of organic material available/supplied by the inflowing raw water; the growth is therefore escorted by an equivalent dying off. It turns liberates organic matter, which becomes available to bacteria at lower depths. In this way, the whole of the degradable organic matter present in the raw water is gradually broken down and converted into water, $CO_2$ and relatively inoffensive inorganic salts such as sulphates, nitrates, and phosphates. The bacteria oxidize part of the food to provide the energy they need for their metabolism, and they convert part of it into cell material for their growth. Thus, dead organic matters are converted into living matter. The dissimilation of products is carried away by the water, to be used again at greater depth by another bacterium.

The bacterial activity is most pronounced in the upper layer of the filter-bed and gradually decreases with depth as food becomes scarcer. When a filter is cleaned by scraping off the top few millimetres layer, the bacteria in the layer are also removed, and a further ripening period is necessary to bring the population of microbes up to the required depth. The bacterial activity below a depth of 30-40 cm it is very small, but biochemical reactions take place converting such microbiological degradation products as amino acids into ammonia and nitrates. The *Schmutzdecke* have a double function, which includes mechanical filtration, the depth of the *Schmutzdecke* can be said to connect to the penetration zone of solid particles, that is, the top 0.5-2 cm of a filter bed (Ranjan 2017). At this depth, the *Schmutzdecke* merges with the deeper biological layer, and filter raw water flows into this zone after passing through the *Schmutzdecke* layer. This deeper zone is not largely a mechanical filtration zone but somewhat a continuation of the area of biological action.

## Filtration processes within the *schmutzdecke* and the biological zone

As per Huisman and Wood (1974),there are four dominant processes which contribute to the purification of the raw water:

Hostile Environment: Conditions found within a slow sand filter are generally unsuitable for the multiplication of intestinal bacteria. Normally used to a human body temperature of 37°C, they do not thrive at temperatures below 30°C.

Competition for food: Food is required for the microbial community for metabolism. Oxidization processes during metabolism consume organic matter in the raw water, including dead pathogens. The filter bed does not usually contain adequate organic matter of animal origin to meet their nutritional needs. Within the upper layers, there is competition for food from other microbes while at lower depths suitable food becomes even scarcer so that they starve, particularly at higher temperatures when their metabolic rate increases.

Predation: Many types of predatory organisms thrive in the upper part of the filter bed and feed on other cells.

Excretion of poisons or toxins: It is reported that the microorganisms in a slow sand filter produce various substances that act as chemical or biological poisons to intestinal bacteria.

The combined effects of this selectively hostile environment result in the death and inactivation of many pathogens. The overall result is a substantial reduction in the number of indicator bacteria such as E. coli, and an even greater proportional decrease in pathogens themselves.

## Biological populations found in *Schmutzdecke* layer

Buzunis (1995) found that the schmutzdecke layer is made up of a variety of microorganisms. These include algae, bacteria, protozoa and small life cells. The types of microorganisms and the relative number of each species are specifically adapted to the characteristics of the raw water source and the environment of the filter. Different types of bacteria are normally found at various depths below the filter surface. Lazarova and Manem (1995) reported that the many research identified the bacterial in *schmutzdecke* by insulated the biofilm from *schmutzdecke* using scanning electron microscopy (SEM). This research found *Pseudomonas stutzeri* bacterial community. Bryan *et al.*, (1999) reported that the *Pseudomonas stutzeri* is Gram-negative bacteria, commonly found in soil, and it also de-nitrifiers because it can change nitrate to nitrogen gas.Also, other studies have shown that the result of DNA isolated from bacteria in *schmutzdecke* has 98% similarity with *Sphingopyxiswit flariensis*. Fitriani *et al.*, (2014) found that in *schmutzdecke* 13 different bacterial isolates based on colony morphology observation is only 11 isolates identified. It because of the amount of DNA extracted is less than 60bp, thus the primary can’t be attached when the annealing process occurs while the nucleotide amplification. The total of 11 isolates identified as *B. subtilissmzd*-1, *S. sciurismzd*-2, *A. baumanniismzd*-3, *B. acidicelersmzd*-5, *B. megateriumsmzd*-6, *B. altitudinissmzd*-7, *B. pumilussmzd*-9, *B. subtilissmzd*-10, *B. subtilissmzd*-11, *B. licheniformissmzd*-12, *dan B. cereus smzd*-13.

## Development of *Schmutzdecke* layer

For the development of the *Schmutzdecke* layer on filter bed, the presence of adequate food, oxygen, and suitable temperatures is required. The bacterial population is limited by the amount of organic material supplied by the inflowing raw water.

## Depth of *Schmutzdecke*layer

Slow sand filters show that the majority of biological processes occur in the top layer of the sand bed. They also cleared that the bacteriological purification occurs mostly in the top 40 cm of the sand bed below the schmutzdecke. Biological activity occurs within this active filtration bed. Below a depth of 30-40 cm, bacterial activity is small, but biochemical reactions take place converting organic materials such as amino acids into ammonia, nitrites, and nitrates. These amino acids are liberated from the bacterial life cycle in the upper filter layer (Huisman and Wood, 1974). This result has been confirmed by test data where oxidation of nitrogenous organic compounds at depths lower than 40 cm was found to be incomplete (Muhammad *et al*, 1996). For irregularly operated sand filters, the depth of biological processes is also dependent on how much water is standing on top of the sand during gap times. A lower water depth means that more oxygen can diffuse to the biological layer, and as a result, the biologically active zone can grow deeper in the sand.

## Keeping the sand bed wet

For the survival of the microbial community within the biological zone, the sand bed must be kept wet. The sand bed is kept wet by sand filter design, where the outlet level is made above the level of the sand. This will be always ensuring that the sand filter bed does not dry out.

### Food supply

For the survival of the microbial community within the biological zone, there needs to be a supply of food in the raw water. Seeding the filter with biologically productive raw water ensures more efficient biological filtration **(**Palmateer *et al.*, 1999).

### Oxygen supply

For the survival of the microbial community within the biological zone, there needs to be a supply of sufficient oxygen demand. Oxygen is used in the metabolism of biodegradable components and the inactivation and consumption of pathogens. If it falls to zero during filtration anaerobic decomposition occurs, with consequent production of hydrogen sulphide, ammonia, and other taste and odour producing substances together with dissolved iron and manganese, which make the treated water unsuitable for washing clothes and other purposes. Huisman and Wood (1974) found that the average oxygen content of the filtered water should not be allowed to fall below 3 mg/l if anaerobic conditions are to be avoided throughout the whole area of the filter bed. This requirement may call for aeration of the raw water to increase its oxygen content or pre-treatment to lower its oxygen demand. Develop a way to allow enough oxygen transfer to sustain the biological layer has been essential in the design of the intermittent slow sand filter.

### Contact time

For satisfactory biochemical oxidation of organic matter by the organisms in the biological layer, enough time must also be allowed to maintain a long enough contact time with the sand bed. About the daily amount of water put through the filter, they found that microbial reductions were greater with a greater residence time within the filter, especially for water retained in the filter bed overnight. The many researchers showed this through taking samples of filtered water at various stages when the filter was re-started after gap time – a significant drop infiltrates quality was noted after the pore volume threshold had been filtered which in their case was 18.3 litres. This showed that water that had been standing in the filter during gap time had a much better quality, and this appears to be largely due to the increased contact time for biological and chemical processes in the sand. Elliott *et al.,* (2008) confirmed that the importance of residence time of water in a filter. During six to eight-week-long studies conducted on the sand filter, filters were fed with surface water spiked with *E. coli, echovirus type 12* and bacteriophages (MS2 and PRD-1). He found that the performance of the filter in reducing microbial concentrations in water fed into the filter depended largely on the amount of time that the filter bed had to ripen, and the daily volume of water put through the filter each day. Also, Jenkins *et al.,* (2009 and 2011) have built on this understanding about the importance of residence time. They investigated the effect of gap time on efficiency at removing viruses, bacteria and turbidity but also looked at other parameters that influence flow rate and therefore residence time, namely hydraulic loading and sand size. They established previous findings on the impact of gap time on water quality. They found that water quality improved with longer residence times (i.e., mean 16 hours) compared to shorter residence times (i.e., mean of 5 hours). They also tested filters with varying levels of hydraulic loading above the sand surface (10, 20 and 30 cm) and two sand sizes (0.17 mm and 0.52 mm). They found that bacteria and virus removal was significantly better for filters with finer sand and those with a lower head, independently from each other and for both short and long-term residence times, but that results were enhanced with longer residence times. The best combination was 0.17 mm sand with 10 cm head over longer residence times.

**Effect of temperature**

The temperature of the water must not be allowed to fall too low for satisfactory biochemical oxidation of organic matter to take place by the microbes in the biological layer. The efficiency of slow sand filtration may also be seriously reduced due to low temperatures, due to the influence of temperature both on the speed at which chemical reactions take place and on the rate of metabolism of bacteria and other microorganisms. At low temperatures, the activity of bacteria consuming protozoa and nematodes drops abruptly, and at the same time the metabolism of the intestinal bacteria themselves slows down, increasing the chance of survival of those that are carried through the bed. The factor by which the numbers of E. coli or other microbes are reduced, which is normally in the range 100-1000, may fall as low as 2 at temperatures of 2°C or less, and chlorination is then essential if the quality of the delivered water is to be maintained.

A schmutzdecke layer takes some time to develop naturally. This is usually at least around 2-3 weeks.

Palmateer *et al.,* (1998) measured the development of a biofilm or schmutzdecke and found that at $21^0$C, it acquired 16 days for the biological film to develop to 85-90% cover. They noted that having a raw water that is more biologically productive will mean that the biofilm will develop more quickly and that the filter will operate more efficiently. Schmutzdecke layer development due to the low hydraulic loading and smaller sand size found in slow sand filters. It mostly develops within the top 0.5-2 cm of the sand filter.

Bellamy *et al.,* (1985a) reported that the filter ripening is a complex process that involves both biological and physical mechanisms. As filtration progresses, biological growth consisting of algae, bacteria, and zooplankton occurs in the sand bed and gravel layer. During this period, the filter does not effectively remove bacteria. It also concluded that a new sand bed will remove 85% of the coliform bacteria in the raw water. As the sand bed matures, the percent removal improves to more than 99% for coliform bacteria. The ripening period for the bio-sand filter is usually one to two weeks. However, for slow sand filters, the ripening process can be accelerated by using synthetic polymers to agglomerate particles in the raw water and accelerate their removal at the filter surface so as to quickly develop the filter cake. However, the addition of chemicals to the sand filter would complicate the originally simple filtration process.

Hirschi and Sims, (1991) reported that the maturity of the sand bed, the development of the *schmutzdecke* is an important process of removing pollutants. The thickness of the schmutzdecke is an increase, thus the filtration efficiency value is raised. Farooq *et al.,* (1994) reported that the formation of *schmutzdecke* or colmation layer on the surface of the sand bed as filtration progresses is considered as the important process of purification mechanism of slow sand filters. Jellison*et al.,* (2000) reported that while successful in removing turbidity and pathogens from drinking water, slow sand filters require ripening periods at the starting of each filter run. The principle of this research was that it should be possible to enhance the ripening of slow sand filters.

Potential ripening agents were screened by assessing their interaction with the surface of filtration media and turbidity particles. Four natural organic polymers and nine synthetic polymers were investigated for their potential to enhance filter ripening of the 13 modifying agents considered, none conclusively sorbed to the filter media, and only one, a synthetic polymer, interacted with kaolin particles. A filter modified with a continuous feed of the polymer ripened successfully and produced water with turbidity below 1.0 NTU in about 24 hours. Most turbidity removal in the treated filter occurred in the *schmutzdecke* rather than within the depth of the filter bed. Hence, the mechanism of enhanced ripening in this case probably was particle agglomeration with resulting acceleration of particle deposition at the filter surface accompanied by straining or attachment to previously removed particles.

Prakash *et al.,* (2003) found that the *Schmutzdecke* development period generally occurs in a few hours to weeks depending on the type of bacteria in raw water and the other microorganisms attached on the sand medium. As long as the length of the filter is operated, the diversity of microorganisms in *Schmutzdecke* also increased. Joubert *et al.,* (2008) reported that the *Schmutzdecke* development period generally occurs in a few hours to weeks depending on the type of bacteria and the other microorganisms attached to the sand medium. Zhu and Bates (2013) reported that the in a fixed-film biological process, biofilms are developed on media such as sand, anthracite, granular activated carbon (GAC), or membranes. A biofilm process mainly consists of two simultaneous steps, substrate diffusion and biological reaction.

## Filtration of bacteria and fine particles

The *Schmutzdecke*is developing where the highest concentration of biomass exists, hence the region where most biological treatment is achieved. Thus, pathogen removal and other impurities removal occur in this region. Ellis (1987) reported that that most of removal of suspended solids, BOD, and coliform organisms occurred at the surface sand layer, "*Schmutzdecke*". When raw water passing to this layer, the organic materials can be removed by conversion into living matter, and the pathogens, protozoa, parasite, and suspended solids are removed(Schuler *et al.,* 1991). Chapetta (2008) observed that the removal of coliforms including *E. Coli* from raw untreated water must then be attributed to some other mechanism inside the slow sand filters that remains invisible and that lies within the sand column itself. The causative agent most likely responsible for the massive amount of coliform removal from untreated water within the slow sand filters is kinetic adhesion of the bacterial cells to the sand itself. The shape and size of the bacterial cell also contribute to the efficacy of particulate adhesion including the porous media that is used. Elliott *et al.,* (2008) showed that microbial reductions improved over time with ripening, but a greater reduction was noted after 30 days. Microbial reductions continued to improve even up to 53 days during the research, indicating that the longer the better and that ripening can take some time.

## Limitations of *schmutzdecke* layer

The efficiency of sand filters slowly reduced as the *schmutzdecke* thickness is increased and thereby reduces the rate of flow through the filter. Ultimately, it is necessary to clean the top layer of the filter. After cleaning of sand water is decanted back into the filter and re- circulated for a few hours to allow a new biofilm to develop. A decline in flow rate is expected due to head-loss accumulation as the filter ripens or matures. Particle accumulation and biological growth in the topmost layer of the media bed is typically responsible for ripening. The concentration of organic substrate to support microbial colonization on the filters that then leads to head loss is another factor that was not constant among the three experiments because the percent PE was not the same. This may have confounded the expected order of the decline in flow rates(Elliott *et al.*, 2008). The highest contribution to head loss in the slow sand filter is located in the top few centimetres of the sand and bottom layers of the *schmutzdecke*. The *schmutzdecke* is found to contribute substantially to the total head loss compared to the sand bed. The *schmutzdecke* acts as a porous filter medium in open filters, preventing the fast clogging of the sand bed. The necessary period for establishment of the *schmutzdecke* and its thickness are important factors affecting head loss development (Campos *et al.*, 2006).

The filter maturation due to thegrowth of the *schmutzdecke* and particle trapping increases head loss and thus decreases filtration rate (Elliott *et al.*, 2015). Adeniran and Akanmu (2013) found that the schmutzdecke is removed when the head loss becomes excessive and the outflow rate becomes slow. After the filter is drained, the schmutzdecke is removed by scraping about 2 cm from the surface of the sand bed. The interval between scrapings depends on the contaminants present in the water and the hydraulic loading rate.

In conclusion, *Schmutzdecke* is the layer of the microbial community that is responsible for purifying the water through thesand bed. As water passes through this biological layer, foreign particles are trapped and essentially eaten by bacteria forms on this layer. Development of *schmutzdecke* layer depends on available microbes in raw water, food supply, oxygen supply, residence time, and wetting of sand bed. Its development depends on the organic matter present in raw water. Generally, 13 types of bacterial community are found in the schmutzdecke layer, in which *Pseudomonas stutzeri* bacteria are dominant. The efficiency of filters reduced as the *Schmutzdecke* thickness is increased.It can be recovered by the cleaning of the top layer of the sand filter.

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