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Bioclogging or **biological clogging** is the clogging of pore space in soil by microbial biomass; their body and their byproducts such as extracellular polymeric substance (EPS). The microbial biomass blocks the pathway of water in the pore space, forming a certain thickness of the impermeable layer in the soil, and it can reduce~~s~~ the rate of water infiltration significantly~~of water remarkably~~.

Bioclogging is observed under continuous ponded infiltration at various field conditions such as artificial recharge ponds, percolation trenches, irrigation channels, sewage treatment systems, constructed wetlands, and landfill liners. It also affects groundwater flow in the aquifer, such as ground source heat pumps, permeable reactive barriers, and microbial enhanced oil recovery. Bioclogging is a significant problem ~~I~~in the situation where water infiltration is hampered ~~of water at an appropriate rate is needed, bioclogging can be problematic~~ and countermeasures such as regular drying of the system can reduce the levels of biocloggingare taken. In some cases, bioclogging can be utilized to make an impermeable layer to minimize the rate of infiltration.

General description

Change in permeability with time

Bioclogging is observed as the decrease in the infiltration rate. A decrease in the infiltration rate under ponded infiltration was observed in the 1940s for studying the infiltration of artificial recharge ponds and the water-spreading on agricultural soils.[1] When soils are continuously submerged, permeability or saturated hydraulic conductivity changes in 3 key stages ~~which was explained as follows. :~~

1. Permeability decreases for 10 to 20 days possibly due to physical changes in the structure of the soil.
2. Permeability increases due to dissolving the entrapped air in soil into the percolating water.
3. Permeability decreases for 2 to 4 weeks due to the disintegration of aggregates and biological clogging of soil pores with microbial cells and their synthesized products, slimes, or polysaccharides.

The 3 stages are not necessarily distinct in every field condition of bioclogging; when the second stage is not clear, permeability just continues to decrease.

Various types of clogging

Kommentiert [m1]: In general, the article is well written and I do not see a particular issue that should prevent this manuscript from being published if the requested editing below is performed. My main comment is that some section requires more depth and explanations and a restructuring of the manuscript will enhance the overall clarity significantly.

Kommentiert [m2]: This is not well connected to the rest. A context is needed.

Kommentiert [m3]: Not only, if there is less water available it will also lead to reduced rates. Please be more specific.

Kommentiert [m4]: I think that this sentence is about the history of studying bioclogging? If so it should be formulated accordingly .

Kommentiert [m5]: Please add since when…

Kommentiert [m6]: Why talk now about clogging which is more general than bioclogging? I would suggest a general statement of few sentence about clogging in the section that could be view as “history of Biolclogging” and removing this section below. Ot just focusing on item 3 in the list.

The change in permeability with time is observed in various field situations. Depending on the field condition, there are various causes for the change in the hydraulic conductivity, summarized as follows.[2]

1. Physical causes: Physical clogging by suspended solids or physical changes of soils such as the disintegration of aggregate structure. Dissolving of the entrapped air in soil into the percolating water is a physical cause for the increase in hydraulic conductivity.
2. Chemical causes: Change in the electrolyte concentration or the sodium adsorption ratio in the aqueous phase, which causes dispersion and swelling of clay particles.
3. Biological causes: Usually bioclogging means the first of the following, while bioclogging in a broader sense means all of the following.
    1. Bioclogging by microbial cell bodies (such as bacteria,[3][4][5][6] algae[7] and fungus[8][9]) and their synthesized byproducts such as extracellular polymeric substance (EPS)[10] (also referred to as slime), which form biofilm[11][12][13] or microcolony aggregation[14] on soil particles are direct biological causes of the decrease in hydraulic conductivity.
    2. Entrapment of gas bubbles such as methane[15] produced by methane-producing microorganisms clog the soil pore and contributes to decreasing hydraulic conductivity. As gas is also microbial byproduct, it can also be considered to be bioclogging.
    3. Iron bacteria stimulate ferric oxyhydroxide deposition which may cause clogging of soil pores.[16] This is an indirect biological cause of the decrease in hydraulic conductivity.

Bioclogging is mostly observed in saturated conditions, but bioclogging in the unsaturated conditions is also studied.[17]

Field observations

Kommentiert [m7]: Of what?

Under ponded infiltration

Kommentiert [m8]: Is this needed for the structure of the article?

Field problems and countermeasures

Bioclogging is observed under continuous ponded infiltration in such places as artificial recharge ponds[18], and percolation trenches.[19] Reduction of infiltration rate due to bioclogging at the infiltrating surface reduces the efficiency of such systems. To minimize the bioclogging effects, pretreatment of the water to reduce suspended solids, nutrients, and organic carbon might be necessary. Regular drying ~~of the system~~ and physical removal of the clogging layer can ~~also~~ be an effective countermeasure~~s~~., however these practices to do not ensure the preventation of bioclogging as it ~~Even if operated cautiously in this way, bioclogging~~ is still likely to occur because of microbiological growth at the infiltrating surface.

Kommentiert [m9]: This sentence does not connect well to the previous sentence.

Septic drain fields are also susceptible to bioclogging because nutrient-rich wastewater flows continuously.[20][21] The bioclogging material in the septic tank is sometimes called biomat.[22] Pretreatment of water by filtration or reducing the load of the system could delay the failure of the system by bioclogging. Slow sand filter system also suffers from bioclogging.[23] Besides the countermeasures mentioned above, cleaning or backwashing sand may be operated to remove biofilm and recover the permeability of sand.

Kommentiert [m10]: "The organic material causing bioclogging is sometimes…"

Kommentiert [m11]: This is too short to stand alone. Please unite all 3 subsections here under "field problems and countermeasures" to what coherent paragraph.

The aspect of countermeasures is very weak. Please extend.

Bioclogging in rivers can impact aquifer recharge, especially in dry regions where losing rivers are common.[24]

Benefits

Bioclogging can have a positive effect in certain ~~cases~~environments on. For example, in the dairy waste stabilization ponds used for the treatment of dairy farm wastewater, bioclogging effectively seals up the bottom of the pond.[25] Similarly, irrigation channels for seepage control may be inoculated with Algae and bacteria ~~may be inoculated~~ to promote bioclogging in ~~irrigation channels for seepage control~~.[26]

Bioclogging is also beneficial in landfill liners such as compacted clay liners. Clay liners are usually applied in landfill to minimize the pollution by landfill leachate to the surrounding soil environment. The hydraulic conductivity of clay liners become lower than the original value because of bioclogging caused by microorganism in the leachate and pore spaces in clay.[27][28] Finally, ~~B~~bioclogging is now being studied to be applied to geotechnical engineering.[29]

Horizontal flow

Bioclogging is observed in constructed wetlands[30] for treating various types of contaminated water. When the vertical flow is applied,[31] it is similar to the previous section. In the constructed wetland with the horizontal flow at the subsurface, preferential flow paths avoiding the clogged part can be observed.[32]

In aquifer

Water withdrawal from the well

Bioclogging can be observed when water is withdrawn from the aquifer (below the groundwater table) through a water well.[33] Over months and years of continued operation of water wells, they may show a gradual reduction in performance due to bioclogging or other clogging mechanisms.[34] Bioclogging may also affect the sustainable operation of ground source heat pumps.[35]

Bioremediation

Biofilm formation is useful in the bioremediation[36] of biologically degradable groundwater pollution. A permeable reactive barrier[37] is formed to contain the groundwater flow by bioclogging and also to degrade pollution by microbes.[38] Contaminant flow should be carefully analyzed because a preferential flow path in the barrier may reduce the efficiency of the remediation.[39]

Oil recovery

In the extraction of petroleum, a technique of enhanced oil recovery is implemented to increase the amount of oil to be extracted from an oil field. The injected water displaces the oil in the reservoir which is transported to recovery wells. As the reservoir is not uniform in permeability, injected water tends to

Kommentiert [m12]: On what?

Kommentiert [m13]: Reducing water loss?

Kommentiert [m14]: To what purpose?

Kommentiert [m15]: In what way? This statement is unclear.

Kommentiert [m16]: This section is unclear. Why not merging it with the benefits section above?

Kommentiert [m17]: Perhaps move it to problems above? I understand that the author wishes to partition the water movement direction into section of different relevance but there is too little material to support this structure in my opinion.

Kommentiert [m18]: I would have moved it to benefits

Also contamination was already addressed earlier – another reason to merge.

go through a high permeable zone, and does not go through the zone where oil remains. In this situation, the bacterial profile modification technique,[40] which injects bacteria into the high permeable zone to promote bioclogging can be employed. It is a type of microbial enhanced oil recovery.