ENHANCING RAINWATER HARVESTING THROUGH PERVIOUS PAVEMENT SYSTEM BASED ON THE PRINCIPLE OF SURFACE FREE ENERGY

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ABSTRACT

Pervious pavements are widely used in stormwater management practices due to their porosity. However, the longevity and infiltration capacity could be greatly reduced with time due to clogging issues. DakeRechsand manufactures pervious bricks from desert sand based on principle of surface-free energy treatment. The pavers are made from desert sand that can withstand against temperatures as high as 100 degrees Celsius and also handling freeze-thaw cycle testing. This product range contains silica as the base material, has good anti-slippery performance when wet. And observations showed that the there is less chance of black ice formation on the brick surface, due to air-permeable propertities of the material. The company has completed hundreds of projects mainly in China. Utilizing breathable desert sand using the surface free energy is something not mastered before and DakeRechsand introduces an eco-friendly, sediment-free, recyclable, and much efficient technology to enhance rainwater harvesting and water conservation.

KEYWORDS

Rainwater Harvesting, DakeRechsand, Pervious Pavement, Breathable Sand, Surface free Energy

1. INTRODUCTION

Since the Industrial Revolution, the global economic wheel moved at a much higher pace than ever before and both the developing and developed countries prospered a lot through the fossil fuel- based industrial economy. However, the environmental and ecological impacts of mass-scale industrialization and fossil fuel consumption must not be ignored. Today the major environmental catastrophes i.e. climate change, deforestation, flooding, and wildfire are occurring, and to combat such disasters, sustainable development and innovation are the need of the hour. As climatic changes are becoming more severe, the weather patterns i.e. wind and precipitation in a local area also change. Since 1960 weather-related extreme events, flooding has caused 60,000 deaths in developing countries mainly in South Asia (Anwar et al., 2019). Sustainable infrastructural development of the urban area is unavoidable.

Moreover, flash flooding (flooding caused by intense rainfall) is the leading cause of weather-related disruption to the transport sector (Dawson et al., 2016). The problem of intense rainwater accumulation on roads, streets, and driveways is acute and the main reason for this is the impermeable surfaces of roads and urban infrastructure that prevent the infiltration of water into the ground. Environmental calamities are becoming more intense with time and there is a need to upgrade urban infrastructure, drainage, and pavement system to cope with the aftermath of heavy rainfall. On July 28, 2012, 50 mm rain fell on Newcastle UK, the transport was canceled on that day because streets were full of water and were unpassable, resultantly the event flooded 1200 homes causing £8m of direct damage to roads and pavements alone (Pregnolato et al., 2017). Therefore, new paradigms to reduce the negative impact of impervious surfaces such as Low Impact Development, Sustainable urban drainage systems, and Sponge City Construction, are considered more sustainable approaches in urban stormwater management.

With storms and heavy rainfall events becoming more frequent, the storage, utilization, and harvesting of rainwater is a sustainable option that not only reduces the runoff of water. Stormwater management practices like permeable pavement systems not only enhance rainwater harvesting and groundwater recharge but are also very efficient in reducing pollution discharge associated with urban runoff (Kamali et al. 2017). In the urban road infrastructure, permeable pavements are playing a significant role from the perspective of rainwater harvesting, water infiltration, and recharging of groundwater which are lacking in traditional impervious asphalt and concrete road surfaces. However pervious pavers vary in features i.e. raw material type, porosity, weight-bearing capacity, water harvesting capacity, withstanding hot/cold temperature, abrasion resistance, anti- slippery and lifespan. Although there are many types of pervious pavement systems yet the basic principle of most of them is the same i.e. porosity.

1.1. Porous Pavements

For the management of stormwater runoff, porous pavement is very popular in urban applications. Porous pavement, as the name implies, enhances the infiltration of stormwater by passing it through the pores present in the pavement towards the storage reservoir. The structure of porous pavement is either monolithic i.e. porous asphalt (consisting mainly of bound granular material containing concrete and asphalt). Installing a porous pavement is a sustainable option when it comes to stormwater management. But due to porous features, this kind of pavement also traps sand and other particulate pollutants. Thus, they not only block the pores but also lead to early sedimentation that reduces the infiltration rate of the pavement to unacceptable levels (Rommel et al., 2001). The infiltration capacity of newly manufactured porous pavement is considered to be around 4500mm/h but after 15-20 years, the infiltration capacity of many porous pavement structures reduces a lot especially after dust accumulation, clogging, and excessive sedimentation (Kadurupokune et al., 2009).

1.2. Permeable Interlocking Concrete Pavement

The principle of permeable interlocking concrete pavement system is also based on porosity, the pavement system consists of solid concrete paving units connect through small joints that usually create an opening in the pavement system. The openings are usually filled with highly permeable small-sized aggregates comprising about 5%-15% of the paver surface (Kolluru, 2014). Permeable interlocking concrete pavement has a less obvious porous surface area as compared with other types of permeable pavements yet the infiltration rate in PICP is quite high. An average interlocking pavement system allows a flow rate of 2500cm/hr (Borst et al., 2010). To some extent, PICP is considered a better choice than porous asphalt and pervious concrete pavement system because of its high-water infiltration capacity, more groundwater recharge, and low maintenance cost but the real issue is the sedimentation and clogging that make such storm

management practices a little less economical and sustainable. PICP is considered far better than porous asphalt in reducing sedimentation after stormwater runoff but years of heavy rainfall lead to the sedimentation on the bedding rocks just below the paver joint (Lucke, 2014)). And these pavers actually address the removal of pollutant and also help with water. Permeable or porous (large pore size) pavers do not treat the runoff much.

Sedimentation and clogging issues sometimes appear within two years after the installation of porous pavement system, which not only is costly to maintain but also leads to road damage, additional infrastructure cost associated with repair, and a general disturbance in transportation.

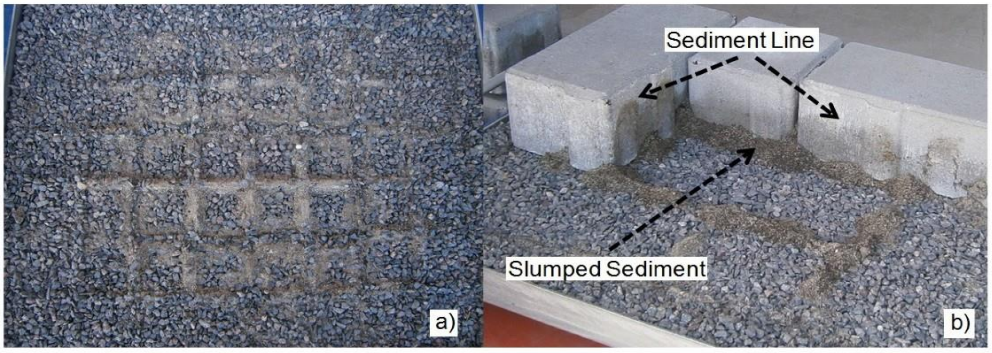

Fig 1: Sediment accumulation on the bedding aggregates in PICP. (Lucke, 2014)

2. DAKERECHSAND'S INNOVATIVE TECHNOLOGY

One sustainable way to manage stormwater is harvesting it, storing it, and then utilizing it instead of directly discharging it into the sewers or receiving waters. This is the principle that Dake Group is offering, but in a more technologically advanced way that brings both environmental and economic benefits.

DakeRechsand, a collaboration between South Africa's Dake Group and The Rechsand Technology Group from Beijing, is a leading fast-paced holdings company with a strong, cohesive vision aimed at creating significant scalable projects by utilizing desert aeolian sand with new technology, new materials, new processes, and new products to create an integrated innovation to form a sustainable solution for the world. The prime focus is on achieving sustainability and water conservation by designing a variety of products like pervious bricks, manholes, path makers, kerbstone, garden pavers, and even an entire road that harvest rainwater by selectively infiltrating water based on the principle of surface free energy. All the products are made up of desert sand, which not only reduces the dependence on asphalt-based roads but also provides efficient raw material to utilize in future projects.

Fig 2: Breathable sand: A prime raw material used in making all paver types, manholes, bricks by DakeRechsand

Figure 3: A pervious paver that can be used in walkways, driveways, and park walkways

Fig 4: A highly pervious manhole, free of sedimentation and clogging maximum water infiltration rate

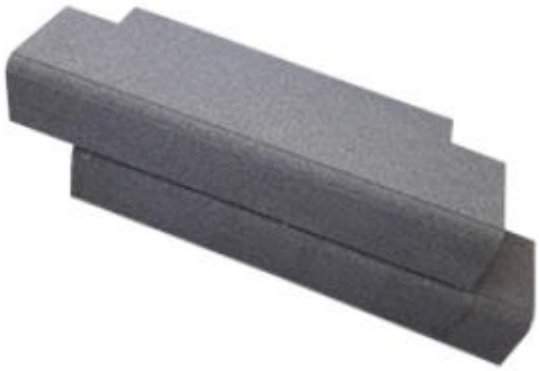

Fig 5: Kerbstone designed from sand and gravel, equally pervious to water.

DakeRechsand is the only company in the world that is manufacturing such patents based on the principle of surface free energy and breathability either it's a pervios paver or breathable sand. The technologies are innovative and focused mainly on overcoming the drawbacks of porous concrete/asphalt pavement by providing something more sustainable. Below listed are few patents by DakeRechsand especially designed to harvest stormwater.

2.1. Principle of Surface Free Energy

It is important to mention that porosity is not the backend principle of DakeRechsand technologies. Instead, all these products function under the principle of surface free energy allowing only water or dissolved solids with the same surface tension as water to infiltrate while the liquid having high viscosity or high surface tension (oil, grease) cannot pass through the surface. Today the porous concrete pavement is very common throughout the world especially in developing countries but the problem associated with porous pavement systems as mentioned earlier is sedimentation which is the reason developed countries are pushing away from porous pavement to sustainably manage stormwater in the long run. In contrast, pervious pavement based on the principle of surface free energy is not widely studied, therefore people fail to understand the benefit it brings and rely on traditional porous concrete pavement systems. Based on the technology used by DakeRechsand in making such effective, pervious, and clogging-resistant pavers below are the promising advantages this technology brings.

2.2. Less Sedimentation

Sedimentation and clogging are the main issues in porous permeable pavements. Due to the pollutant washed-off after the rain, the sand, dust, and other particles are likely to enter the pores. Some are permanently trapped inside, thus reducing the infiltration capacity of the pavement. Untimely clogging reduces the lifespan of a porous paver and another alarming issue is that as sediments build up in between the pavement it reduces the capacity of the system to harvest a high quantity of rainwater (Andres-Valeri et al., 2018). To combat the issue of sediment accumulation, DakeRechsand provides a promising solution in the form of full-surface pervious pavers. These pavers are with micro-scale pores and treated with high surface free energy, allow water to pass through. In this way, dirt that remains on the surface can be easily removed by manual, regenerative-air street sweeping and automatic sweeping methods. While in the case of porous concrete and interlocking concrete pavement structure, the pore structure of the concrete influence

clogging in a way that particles build up and block the interconnecting pores. Even a study stated that the potential of clogging is associated with the tortuosity of the connected pore, greater tortuosity results in more clogging (Razzaghmanesh et al., 2018). Therefore, DakeRechsand introduces a clogging resistant, non-porous permeable paver with desert sand used as primary raw material along with gravels and bonding gel which do not allow for clogging or sedimentation.

2.3. High infiltration Capacity and Longevity

Pervious pavers designed to manage large quantities of stormwater in a short time are more effective not only in harvesting water but also in storage and filtration. All the products designed by DakeRechsand are highly pervious to stormwater with more infiltration capacity than traditional porous asphalt and PICP. In case of heavy rainfall, the pavers can handle rain with a capacity of 720k/hr. Overall a 20% natural degradation of permeable pavement system is expected with time however these pavers are more resistant to external conditions i.e. can withstand heavyweight, extreme hot/cold temperatures, and heavy rainfall without impacting the infiltration capacity and longevity. DakeRecksand gives a warranty of twenty-five years on all their products yet the raw material is also recyclable. It is very easy to replace the pavement once it is degraded as all the raw materials are recyclable including the down gravel and 5mm thick top layer.

Urban cities that enhance rainwater harvesting as much as possible without impacting the transportation sector. For effective storm management, the pavement system must provide the necessary infiltration capacity which in the case of porous concrete and PICP is highly reduced because of excessive sedimentation and clogging with time (Kayhanian et al., 2019). Due to high infiltration capacity, the benefit it brings includes, no surface ponding making travel comfortable even in rainy hours, and no ice formation on the surface as the infiltration capacity and air permeable.

2.4. Breathable Desert Sand: The primary raw material

Porous asphalt, pervious concrete, and PICP have one drawback in common: the porosity that can lead to sediment formation. So, instead of basing the entire technology on concrete, cement, or asphalt (the raw material in conventional pavements), DakeRechsand uses specially manufactured silica sand as the base material that brings multiple economic and environmental benefits. If we build an entire road out of asphalt, cement, and concrete, the longevity of the surface is highly affected by the crack formation in pores and rutting. This does not cause permanent road damage but also blocks the already present pores. While if we talk about pavers containing breathable Desert Sand, the longevity will not be reduced as crack and pore-blocking are not the issues anymore. Secondly, the raw material acquisition is easy. Instead of relying on bituminous (the liquid binder that holder asphalt together), a patented adhesive is used by DakeRechsand that holds the desert sand and gravel in place. The desert sand is a very fine-grained material that only allows water to pass through the base on the principle of selective permeability. This manufactured sand is breathable that allows air to pass through it, therefore, there is no chance of algal formation on the water once it is harvested. The breathable sand does not cause water stagnation because the material absorbs water quickly based on the surface free energy and it's the breathable sand that makes this technology unique, more sustainable, and pollution-free.

2.5. No Black Ice Formation

High altitude areas are more and snowfall usually. The heavy rain and snow turn the road more slippery that's why a construction material that can provide resistance against slippery roads is required to reduce the physical hazard. All the pavement designs by DakeRechsand are free of black ice formation. Whenever snowfall on pavements, it does not get freeze neither the surface gets slippery because of the fine texture of desert sand. Snow, black ice forms when rain or snow falls , black ice which is highly transparent, slippery, and is the result of air pollution caused by anthropogenic activities. The pavers, manholes, kerbstone, and all other products from Rechsand technology are both anti-slippery and anti-sticky. Even if oil and snow remain on the paver surface, it does not get slippery, and the same is the case with sticky objects like bubble gum or gel. One can wipe out dust, oil, bubble gum, and snow both mechanically and automatically.

2.6. Performance at extreme hot and cold temperature

Another critical element in stormwater management practices is the performance of permeable pavement at extreme temperatures. As mentioned earlier that desert sand is the basic building block of all pavers designed by the Rechsand group, this contains no glue, chemicals, and any other material that can react at high temperatures and degrade the performance of the pavement block. This makes silica a better choice over concrete and asphalt which are used in porous pavements because they can handle high temperatures. Even at 100 degrees Celsius, the silica-based pavement does not degrade either structurally or operationally. Similarly, low temperature cannot cause any damage to the pavement surface, all the pavers, bricks, and manholes can handle 75 thaw cycles of cold as they are free of cement there is no chance of hole or crack

formation on the surface. Porous concrete, once clogged by sediments becomes more vulnerable to freeze and thaw cycles (Truegrid, 2019). The silica-based permeable bricks do not allow snow to turn into ice because the surface of the brick absorbs water quickly and air permeable. This makes them a perfect choice for low-temperature, snowy regions where the main issues associated with road construction are accidents.

3. SUCCESSFUL PROJECTS

With 15 manufacturing facilities and a yearly manufacturing capacity of 20 Million Square Meters, a variety of products are manufactured by DakeRechsand. They range from FOSUN (oil and water permeable), IDER (water permeable and breathable) to LUSE (breathable, water, and soundproof). To this day, DakeRechsand has completed numerous projects and dozens are underway. Multiple projects have been completed in China include Changan Street, Beijing National Aquatics Centre, Taichung Mass Rail Transit, Beijing National Indoor Stadium, China Pavillion for Shanghai World Expo 2010, and Beijing Olympic National Stadium. Regardless of the 5mm thickness of the upper layer, DakeRechsand guarantees that an entire road can be built by this material without any impact on the longevity, infiltration capacity, and weight-bearing capacity. As there is no stagnation, the surface of the paver/brick does not allow water to stay on it therefore this technology is not only confined to pavements, sideways, or walkways. For centuries, asphalt and concrete are conventionally used in making roads and their limitations like sedimentation and cracking make them less sustainable when it comes to rainwater harvesting. The world needs something more sustainable and DakeRechsand is providing it and currently, dozens of projects are under the way in different countries.

4. CONCLUSION

Stormwater management is very critical for water conservation especially in today's time where water pollution and shortage are serious environmental issues. Old and conventional methods of rainwater harvesting are there but the future needs more innovative technologies that not only enhance water conservation but are also economical, clean, and can be installed in all infrastructure. The recyclable and easy-to-install products of DakeRechsand can transform the future perception of rainwater harvesting. Permeable surfaces will always remain in demand, yet common raw materials like asphalt and concrete are going to fall short let alone the sedimentation, water stagnation, and abrasion issue they cause. No one in the world has mastered surface-free energy in the context of permeability, the way DakeRechsand manufactured their products and successfully implemented them in the real world will open a gateway for many more technological advancements to come.

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REFERENCES

[1] Anwar, M., Iftikhar, M., KhushBakhat, B., Sohail, N., Baqar, M., Yasir, A., &Nizami, A. (2019). Sources of Carbon Dioxide and Environmental Issues. Sustainable Agriculture Reviews, 13-36. https://doi.org/10.1007/978-3-030-29298-0_2

[2] Andres-Valeri, V., Juli-Gandara, L., Jato-Espino, D., & Rodriguez-Hernandez, J. (2018). Characterization of the Infiltration Capacity of Porous Concrete Pavements with Low Constant Head Permeability Tests. Water, 10(4), 480. https://doi.org/10.3390/w10040480

[3] Borst, M., Rowe, A.A., Stander, E.K., and O'Connor, T.P., Surface Infiltration Rates of Permeable Surfaces: Six Month Update (November 2009 through April 2010), EPA/600/R-10/083, Office of Research and Development, National Risk Management Research Laboratory—Water Supply and Water Resources Division, Edison, NJ, http://permanent.access.gpo.gov/gpo25416/ ZyPDF.pdf
[4] Dawson, R. J., Thompson, D., Johns, D., Wood, R., Darch, G., Chapman, L., ...& Hall, J. W. (2018). A systems framework for national assessment of climate risks to infrastructure. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 376(2121), 20170298.
[5] Ferguson, B. (2005). Porous pavements. CRC Press.
[6] Kayhanian, M., Li, H., Harvey, J., & Liang, X. (2019). Application of permeable pavements in highways for stormwater runoff management and pollution prevention: California research experiences. International Journal Of Transportation Science And Technology, 8(4), 358-372. https://doi.org/10.1016/j.ijtst.2019.01.001
[7] Kazemi, F., & Hill, K. (2015). Effect of permeable pavement base course aggregates on stormwater quality for irrigation reuse. Ecological Engineering, 77, 189-195. https://doi.org/10.1016/j.ecoleng.2015.01.020
[8] Kadurupokune, N., &Jayasuriya, N. (2009). Pollutant load removal efficiency of pervious pavements: is clogging an issue? Water science and technology, 60(7), 1787-1794.
[9] Kolluru, Hemanth&Madduri, Saicharan. (2014). Review on permeable pavement systems.
[10] Lucke, T. (2014). Using Drainage Slots in Permeable Paving Blocks to Delay the Effects of Clogging: Proof of Concept Study. Water, 6(9), 2660-2670. https://doi.org/10.3390/w6092660
[11] Pregnolato, M., Ford, A., Wilkinson, S., & Dawson, R. (2017). The impact of flooding on road transport: A depth-disruption function. Transportation Research Part D: Transport and Environment, 55, 67-81. https://doi.org/10.1016/j.trd.2017.06.020
[12] Rommel, M., Rus, M., Argue, J.R., Johnston, L., Pezzaniti, D., 2001. Carpark with "1 to 1" (impervious/permeable) paving: performance of "Formpave" blocks. In: Reprints of the 4thNovatech Conference, Lyon, France.
[13] Truegrid. (2019). POROUS ASPHALT AND CONCRETE POSE BIG PROBLEMS [Blog]. Retrieved 15 April 2021, from https://www.truegridpaver.com/porous-asphalt-and-concrete/#:~:text=These%20cycles%20cause%20water%20trapped,levels%20of%20sulfate%20in%20th em.

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