REVIEW OF PERMEABLE PAVEMENT SYSTEMS IN MALAYSIA CONDITIONS

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Abstract: The intention of this review paper is to summaries the wide-range but diffuses literature on mainly permeable pavement systems (PPS), highlight current trends in research and industry, and to recommend future areas of research and development. Permeable pavements are alternatives to traditional impervious asphalt and concrete pavements.

Interconnected void spaces in the pavement allow for water to infiltrate into a subsurface storage zone during rainfall events with 3000 mm/hr. Infiltration of stormwater runoff reduces runoff peaks and runoff volumes as the climate of Malaysia is equatorial with high humidity. It has an annual rainfall volume of 320 billion cubic meters (bcm) for Peninsular Malaysia; 194 bcm for Sabah, and 476 bcm for Sarawak.

The development of PPS as an integral part of sustainable drainage systems is reviewed in the context of traditional and modern urban drainage. Permeable pavements can operate as efficient hydrocarbon traps and powerful in-situ bioreactors. Particular highlight is given to detailed design, maintenance and water quality control aspects. The most important target pollutants are hydrocarbons, heavy metals and nutrients. The advantages and disadvantages of different PPS are discussed with the help of recent case studies.

The latest innovations are highlighted and explained, and their potential for further research work is outlined. Recent research of this new type of permeable pavement using honeycomb shaped modular from recycled polyvinyl chloride, PVC can store and collect rain, provide erosion and sediment control, effectively convey and deliver water, and protect natural areas is on the development. This recycling pavement system is shows potential.

Keywords*:* Porous pavement, Sustainable drainage system, permeable pavement

OUTLINES

Country background

Malaysia is located in South-East Asia between latitudes 1° and 7°N and longitudes 110° and 119°E. It consists of Peninsular Malaysia bordered to the North by Thailand, by the South China Sea and Singapore to the South, and the Indonesian island of Sumatra to the East. The States of Sabah and Sarawak, which are situated on the north-western coast of Borneo, are separated from Peninsular Malaysia by 530 km of the South China Sea and share common borders with Brunei Darussalam and Indonesia.

The climate of Malaysia is equatorial with high humidity, and is characterised by the annual southwest (April to October) and northeast (October to February) monsoons. It has an annual rainfall volume of 320 billion cubic meters (bcm) for Peninsular Malaysia; 194 bcm for Sabah, and 476 bcm for Sarawak.

Sustainable drainage systems (SUDS)

Most cities in the developed countries rely on pipe network systems, which have been widely developed in the 19th century. Traditional systems capture storm runoff, and subsequently distributed it to nearby watercourses or sewer systems. Some of these systems have become ineffective and inefficient. Furthermore studies conducted by Schluter and Jefferies (2004), they are usually very expensive.

Instead of focussing on 'end-of-pipe' treatment, SUDS challenge the traditional approach of wastewater treatment by optimising the resource utilisation and development of novel and more productive technologies (Scholz, 2006).

Harvesting, storing, treating and recycling of runoff

Study by Astebol et al., (2004) said that the management of runoff in urban areas has taken a 'green' approach due to the emergence of SUDS, which collect, store, treat, redistribute and recycle water. Examples of these techniques are swales, filter strips, wetlands and ponds.

A central element of sustainable storm water management is the utilisation of storm water as a resource. In countries such as Malaysia, Norway, Sweden and Denmark, water in open systems is used recreationally and in the development of ecosystems and landscapes.

PAVEMENT SYSTEMS

Applications and challenges

Permeable pavement systems (PPS) are suitable for a wide variety of residential, commercial and industrial applications, yet are confined to light duty and infrequent usage, even though the capabilities of these systems allow for a much wider range of usage. Where there is any concern about the possible migration of pollutants into the groundwater, Wilson et al., (2003) said that PPS should be constructed with an impermeable membrane, and the treated storm water should subsequently be discharged into a suitable drainage system. Common applications of PPS are as follows: (a) vehicular access: residential driveways, service and access driveways, roadway shoulders, crossovers, fire lanes and utility access; (b) slope stabilisation and erosion control; (c) golf courses (cart paths and parking); (d) parking (mosque, employee, overflow and event); (e) pedestrian access; (f) bicycle and equestrian trails; and (g) land irrigation.

Permeable pavements

Permeable pavements are alternatives to traditional impervious asphalt and concrete pavements. Interconnected void spaces in the pavement allow for water to infiltrate into a subsurface storage zone during rainfall events. In areas underlain with highly permeable soils, the captured water infiltrates into the sub-soil. In areas containing soils of lower permeability, water can leave the pavement through an underdrain system. Water that passes through and leaves the pavement is referred to as exfiltrate.

Nearly all permeable pavement types have the same general structures as in Figure 1. Pervious material and fill are considered surface layer or cover. This is the top layer that drivers and users see. It is identified by the type of pavement used, such as permeable concrete, permeable interlocking concrete pavers filled with gravel, or segmental plastic pavers to be filled with grass. More on pavement type follows in this section.

Beneath surface layer is the gravel base. Most pavement types, with the notable exception of permeable concrete, need a gravel or aggregate support layer to bear vehicles. It also stores water during and immediately after a storm event. Despite the fact that permeable concrete does not need an aggregate base layer for structural support, such a layer is often included in permeable concrete designs so that additional water can be stored.

Sub base is the layer soil layer immediately below the base layer. The sub base is necessarily compacted during construction of the permeable lot. It is also referred to as in situ or underlying soil.

Lastly are the underdrains which are typically small plastic pipes. These drainage lines are located at or near the bottom of the sub base to collect water and convey it to the storm sewer network. Underdrains are most often used when permeable pavements are located in soils that contain clay and high water table.

They are several different types of permeable pavement exist, and the main differences among each pavement type are in the total pore space, spatial arrangement of the underlying pervious layers, and structural strength. The most common types include permeable concrete (PC), permeable asphalt (PA), permeable interlocking concrete pavers (PICP), concrete grid pavers (CGP), and plastic grid pavers (PG). Figure 2 depicts several of these pavement types, which are further discussed.

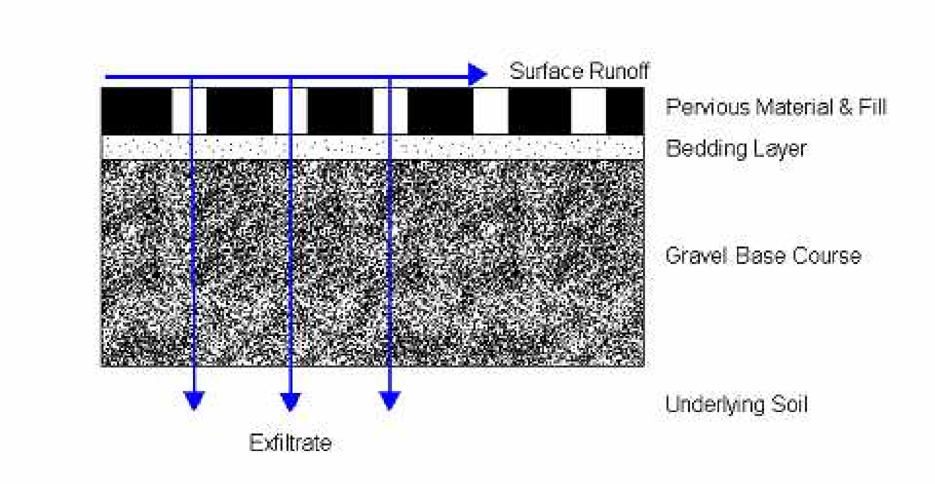

Figure 1: Cross section of a typical block paver permeable pavement installation without underdrains

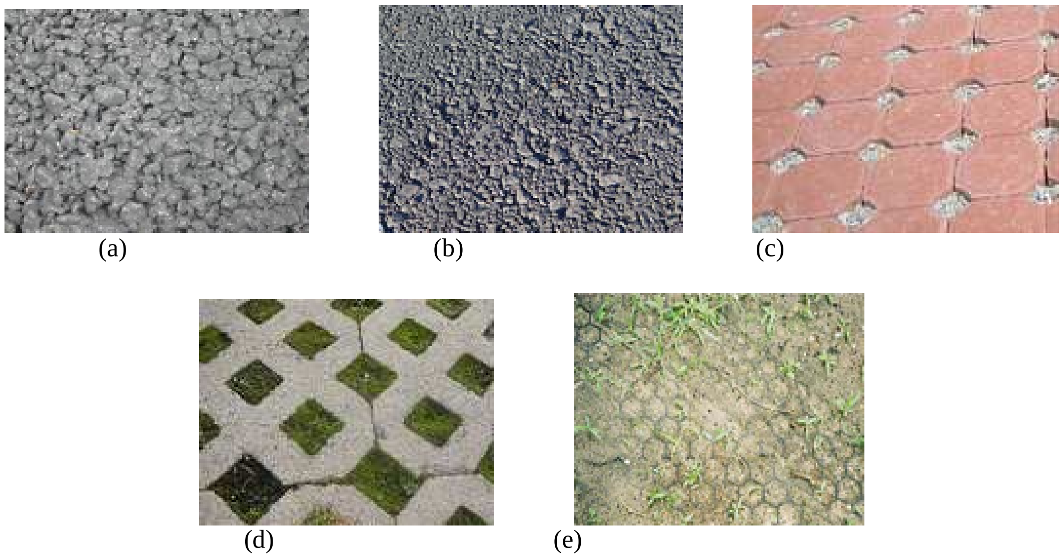

Figure 2: (a) Permeable Concrete. (b) Permeable Asphalt. (c) Permeable interlocking concrete pavers with pea gravel fill. (d) Concrete grid pavers with topsoil and grass fill. (e) Plastic reinforcement grid pavers with earth and grass fill.

Permeable concrete is a mixture of Portland cement, fly ash, washed gravel, and water. The water to cementitious material ratio is typically 0.35 – 0.45 to 1 (NRMCA, 2004). Unlike traditional installations of concrete, permeable concrete usually contains a void content of 15 to 25 percent, which allows water to infiltrate directly through the pavement surface to the subsurface. A fine, washed gravel, less than 13 mm in size (No. 8 or 89 stone), is added to the concrete mixture to increase the void space (GCPA, 2006). An admixture improves the bonding and strength of the pavements. These pavements are typically laid with a 10 to 20 cm thickness and may contain a gravel base course for additional storage or infiltration. Compressive strength can range from 2.8 to 28 MPa (400 to 4,000 psi) (NRMCA, 2004).

Permeable asphalt consists of fine and course aggregate stone bound by a bituminous-based binder. The amount of fine aggregate is reduced to allow for a larger void space of typically 15 to 20 percent. Thickness of the asphalt depends on the traffic load, but usually ranges from 7.5 to 18 cm. A required underlying base course increases storage and adds strength (Ferguson, 2005). Minimal amounts of permeable asphalt have been used in North Carolina.

Concrete pavers conform to ASTM C 1319, Standard Specification for Concrete Grid Paving Units (2001a), which describes paver properties and specifications. CGP are typically 90 mm (3.5 in) thick with a maximum 60 × 60 cm dimension. The percentage of open area ranges from 20 to 50 percent and can contain topsoil and grass, sand, or aggregate in the void space. The minimum average compressive strength of CGP can be no less than 35 MPa. A typical installation consists of grid pavers with fill media, 25 to 38 mm of bedding sand, gravel base course, and a compacted soil subgrade (ICPI, 2004).

Plastic reinforcement grid pavers, also called geocells, consist of flexible plastic interlocking units that allow for infiltration through large gaps filled with gravel or topsoil planted with turfgrass. Sand bedding layer and gravel base-course are often added to increase infiltration and storage. The empty grids are typically 90 to 98 percent open space, so void space depends on the fill media (Ferguson, 2005). To date, no uniform standards exist; however, one product specification defines the typical load-bearing capacity of empty grids at approximately 13.8 MPa. This value increases up to 38 MPa when filled with various materials (Invisible Structures, 2001).

SUDS such as PPS have evolved from a growing recognition that traditional storm water management systems have limitations due to growing rates and volumes of storm water runoff, mainly caused by increased urbanisation and changing weather patterns (Schluter and Jefferies, 2004 and Dierkes et al., 2002).

Permeable pavement designs vary greatly for example; it shows a modern permeable pavement tanked system. The general principle of PPS is simply to collect, treat and infiltrate freely any surface runoff to support groundwater recharge. In comparison to traditional drainage systems, storm water retention and infiltration is a sustainable and cost effective process, which is suitable for urban areas (Dierkes et al., 2002, and Andersen et al., 1999). Moreover, PPS have many potential benefits such as reduction of runoff, recharging of groundwater, saving water by recycling and prevention of pollution (Pratt et al., 1999).

PPS have not only been established as a SUDS solution, but also as a technology for pollutant control concerning surface runoff from areas used as roads or parking spaces, where contaminated water may infiltrate into the underlying soil. Harmful pollutants such as hydrocarbons and heavy metals in surface runoff have the potential to endanger soil and groundwater resources when they are not sufficiently biodegraded and/or removed during infiltration (Brattebo and Booth, 2003 and Dierkes et al., 2002).

Reductions in suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and ammonia levels in comparison to highway gullies not only demonstrate the high treatment efficiency of PPS, but also that there is no need for frequent maintenance, unlike with gully pots (Pratt et al., 1999).

Moreover, hydrocarbon pollution and mineral oil deposition onto urban surfaces have been problems most effectively addressed by PPS. Research has also shown that the structure itself can be used as an effective in-situ aerobic bioreactor (Pindado et al., 1999)

Porous pavements

The focus of this review paper is on PPS. However, porous pavements are also briefly reviewed to provide the reader with a more comprehensive overview of various pavement systems. Porous pavements have been developed to reduce the runoff rates and growing volumes of storm water collected in urbanised areas. They should meet storm water demands while providing a hard surface, which can be utilised in urban areas (Schluter and Jefferies, 2004 and Scholz, 2006).

Porous asphalt or macadam pavement looks similar to conventional asphalt, but is relatively porous. It consists of open-graded asphalt and concrete over an open-graded aggregate base located above well-draining soil.

Porous concrete pavement contains aggregates and a Portland cement binder. The porosity is provided by the omission of fine aggregates. Modular interlocking concrete blocks of the internal drainage cell type are pre-cast or cast in-place lattice or castellated pavers of concrete or plastic, which contain open cells. Soil mixed with grass seeds or porous aggregates usually fill the cells.

Modular interlocking concrete blocks with external open drainage cells are also available on the market. Open cells are formed when blocks are assembled in an interlocking manner and filled with clean gravel.

Block paving stones made of specially designed porous concrete (i.e. polymer-modified porous concrete) exhibit better fatigue behaviour than those without polymers said Pindado et al., (1999). Yet it has been shown that these improvements decrease for low values of stress levels, and sometimes appear to be negligible in the case of traffic loads on main and highway roads.

These concrete products can be used as pollution sinks, because of their particle retention capacity during filtration. The high porosity of the special concrete leads to good infiltration and air exchange rates. Dierkes et al., (2002) note that filtered out pollutants can sometimes be removed by cleaning of the pavement.

Porous asphalt and porous concrete pavement systems are prone to clogging usually within three years after installation. Due to clogging of the voids, these systems can experience a loss of porosity. The main causes of clogging are due to: (a) sediment being ground into the porous pavement by traffic before being washed off; (b) waterborne sediment, which drains onto pavements and clogs pores before being washed off; (c) shear stress caused by numerous breaking actions of vehicles at the same spot, which results in collapsing pores.

Once totally clogged, these systems have to be removed entirely and subsequently replaced. Frequent replacement renders these types of systems impractical and expensive. Modular interlocking concrete blocks have also the potential to be clogged by sediment and produce a low quality effluent. Therefore, PPS are preferred for most applications.

DESIGN

Lifespan

The lifespan of porous asphalt, porous pavement or permeable surfaces, in general, depends predominantly on the size of the air voids in the media. The more possibilities for oxidation, the less durability can be achieved (Choubane et al., 1998).

It can be expected that the life of a PPS is shorter than that of an impermeable pavement due to deterioration by runoff, air infiltration, and subsequent stripping and oxidation, as well as hardening of binder. Recent work by Mallick et al., (2003) has indicated that coarsely graded Superpave mixes can be excessively permeable to water at air void levels of approximately 6%.

Four commercially available PPS were evaluated by Booth et al., after six years of daily parking usage for structural durability, ability to infiltrate precipitation, and impacts on infiltrate water quality. All pavement systems showed no major signs of wear. Virtually all rainwater infiltrated through the PPS, with almost no surface runoff. The infiltrated water had significantly lower levels of copper and zinc than the direct surface runoff from the asphalt area.

Aggregate components

The PPS (Figure 1) comprises four distinct components: (a) pavers and bedding layer; (b) unsaturated zone of the base material; (c) saturated zone of the base material; and (d) sub-grade.

Various aggregates can be incorporated into PPS. For example, Nishigaki (2000) described specially designed blocks for permeable paving using recycled melted slag. No metal leaching was detected in practise.

Geotextiles

Geotextiles help to prevent sand from migrating into the base of PPS. In a permeable bituminous-stabilized base course, the presence of geotextile helps to reduce the rutting depth and rate of block breakage, maintaining a good level of pavement serviceability such as easy cleaning. A geotextile with a fibre area weight of 60 g/m^2 is usually applied (Omoto et al., 2003). Furthermore, Newman et al. (2004) said that most geotextiles can help to retain and degrade oil, if clogging (e.g. silting) is not a problem.

Hydrology and hydraulics

Tests have shown that evaporation, drainage and retention within the permeable structures were mainly influenced by the particle size distribution of the bedding material, and by the retention of water in the surface blocks (Andersen et al., 1999 and Scholz, 2006).

Movement of water through the porous pavement installation is controlled by surface runoff, infiltration through the pavement stones, percolation through the unsaturated zone, lateral drainage at the base and deep percolation through the sub-grade. There are three possible fates for precipitation reaching the surface of a PPS installation (Scholz, 2006 and James and von Langsdorf, 2003): (a) infiltration to the base material where water that leaves the bottom or sides of the permeable pavement and enters the soil. Water exfiltrates from the pavement base layer. It infiltrates the surrounding soil; (b) evaporation where water stored in puddles on an impermeable surface or temporarily trapped near the surface of permeable pavement will eventually evaporate to the atmosphere. If plants aid in the release of water to the atmosphere, as some permeable pavements are designed to be vegetated this process is termed evapotranspiration; and (c) runoff (overland flow) where amount of water leaving the surface of the pavement. This water enters the storm sewer network.

In designing a permeable pavement installation, it is fundamentally important to provide and maintain surface infiltration and storage capacity to allow an adequate volume of storm water to be captured and treated by the facility. James and von Langsdorf (2003) describe the underlying method and function of a computer programme, which uses the United States Environmental Protection Agency Storm Water Management Model for the hydraulic design of permeable pavement installations.

In comparison to conventional asphalts, permeable and porous pavements provide more effective peak flow reductions (up to 42%) and longer discharging times. Abbot and Comino-Mateos, 2003 and Pagotto et al., 2000) said that there is also a significant reduction of evaporation and surface water splashing.

Maintenance to enhance infiltration

Infiltration through the permeable pavement stones and the bedding layer is usually modelled using the complex Green–Ampt equations, which have physically based parameters that can be predicted. James and von Langsdorf (2003) found that infiltration is thus related to the volume of water infiltrated, and to the moisture conditions in the pavers and bedding layer.

Percolation or trickling represents the vertical flow (by gravity alone) of water from the unsaturated zone (i.e. voids filled with air) to the saturated zone (i.e. voids filled with water) of the base layer, and is the only inflow source to the saturated zone assuming that there is no water exchange with the surrounding environment below the ground level. Base layer discharge represents lateral flow from the saturated zone of the base to the receiving water. Deep percolation represents a lumped sink term for not quantified losses from the saturated zone of the base. Two primary losses are assumed to be percolation through the confining layer and lateral outflow to somewhere other than the receiving water.

Concrete grid pavers and permeable interlocking concrete pavers were tested with pavement ages ranging between 0.5 and 20 days. Analysis of the data showed that maintenance for example cleaning of pavers at the end of each experiment improved permeability on 13 out of 14 sites at a confidence level of 99.8%. Sites built in close proximity to loose fine particles had infiltration rates significantly less than sites free of loose fines. Even the minimum existing infiltration rates were comparable to those of a grassed sandy loam soil as shown in study by Bean et al. (2004). Furthermore, the impact of maintenance on the environment was not sufficiently discussed.

Caoi et al. (1998) provided a method to determine the amount of infiltration liquid, and the storage capacity of a permeable base relative to the time of retention and degree of saturation associated with the characteristics of the base. Their guidelines contain a step-by-step process for engineers to select the best pavement option in terms of base materials and gradations for the given drainage, sub-grade strength conditions, and the criteria for maximum allowable rutting.

Infiltration supports groundwater recharge, decreases groundwater salinity, allows smaller diameters for sewers (resulting in cost reduction) and improves water quality of receiving waters, because pollutants and high peak flow are effectively controlled. On the other hand, booth studies from Dierkes et al. (2002) and Scholz (2006) said that pollutants in runoff originating from domestic and industrial emissions, and traffic threaten soil and groundwater, if they are not removed from runoff before it infiltrates into the ground.

WATER QUALITY

Pollutants

Pollution which presents on the road and car park surfaces as a result of oil and fuel leaks, and drips, tyre wear, and dust from the atmosphere. This type of pollution arises from a wide variety of sources and is spread throughout an urban area also known as diffuse pollution. Rainwater washes the pollutants off the surfaces.

Conventional drainage systems, as well as attenuation tanks, effectively concentrate pollutants, which are flushed directly into the drainage system during rainfall and then into watercourses or groundwater. The impact of this is to reduce the environmental quality of watercourses.

Impervious surfaces have a high potential for introducing pollution to watercourses. Possible water quality variables of concern include the following as stated in D'Arcy et al. (1998) and NCDENR (2005): (a) sediment and suspended solids (including phosphorus and some metals); (b) organic waste with high biochemical oxygen demand; (c) dissolved nutrients and pollutants (including nitrogen, heavy metals, solvents, herbicides and pesticides); and (d) oil and grease;

Five processes that affect the concentration of pollutants in the soil's unsaturated zone: sorption, filtration, degradation, volatilization, and water transport. Sorption tends to be the dominant process, and most pollutants will either be sorbed to soil particles or to organic matter. Stormwater pollutants can also be adsorbed onto surrounding sediments in the stormwater before they infiltrate into the soil. Mikkelsen et al. (1994) compiled research data showing that approximately 50 percent of the heavy metal load in stormwater could be removed through either sedimentation or filtration.

Permeable pavements have a good track record at removing suspended solids and nitrogen. However, PPS, which do not rely on below ground infiltration and the use of an underdrain system, will not be successful in the removal of nitrogen. When an underdrain system is incorporated into the pavement design, storm water tends not to infiltrate into the soil, but into the underdrain, where it can be denitrified or removed by plant uptake (NCDENR, 2005).

Dierkes et al. (2002) summarised possible ranges of pollutant concentrations in rain, and roof and road runoff, taken from more than 60 sites throughout Europe. Rain may contain 5-day biochemical oxygen demand (1–2 mg/l), sulphate (0.56–14.40 mg/l), chloride (0.2–5.2 mg/l), ammonia (0.1–2.0 mg/l), nitrate (0.l–7.4 mg/l), total phosphate (0.01–0.19 mg/l), copper (1–355 mg/l) and zinc (5–235 mg/l).

Another laboratory study by Fach and Geiger, (2005) examined pollution removal rates of Cd, Zn, Pb, Cu for permeable concrete block paving and three variations of concrete block pavers; one with wide infiltration pores (29mm), another with narrow pores (3mm), and pavers with a crushed brick substrate infill. Permeable concrete have the highest heavy metal removal rate (96.5% average) followed by block paving with brick substrate infill (92.9% average). No significant differences between the narrow infiltration pores and the wide pores were observed (63.1% and 78.6% average removal rates, respectively). When set over a 4 cm crushed basalt or brick substrate roadbed and a 40 cm limestone base course, average pollution removal rates for all pavements and substructures were very high, ranging from 96 to 99.8 percent.

Hydrocarbons

Oil and diesel fuel contamination is frequently detected on asphalt and other non-permeable surfaces. In comparison, these contaminants were not detected on PPS surfaces assessed by Bratterbo and Booth (2003). Hydrocarbons can endanger soil and groundwater, if they are not removed sufficiently during infiltration through the surface layer (Dierkes et al., 2002). Many pollutants such as polycyclic aromatic hydrocarbons, metals, phosphorous and organic compounds are absorbed onto suspended solids. Models have been designed to estimate the suspended solids load and its dynamics during rainfall events, leading to better understanding of receiving waters being polluted by hydrocarbons (Rossia et al., 2005).

Permeable pavements can operate as efficient hydrocarbon traps and powerful in-situ bioreactors. Coupe et al. (2003) found out that a PPS specifically inoculated with hydrocarbon-degrading micro organisms does not successfully retain a viable population of organisms for the purpose of increased hydrocarbon degradation over many years. Naturally developed microbial communities (i.e. no inoculation with allochthonous microorganisms) degrade oil successfully.

For the successful biodegradation of polycyclic aromatic hydrocarbons, certain environmental conditions need to be met. Degradation takes place when prolonged aerobic, sulphate reducing and denitrifying conditions occur (Lei et al., 2005). Very large hydrocarbon spills can be contained due to absorption processes within the pavement.

Wilson et al. (2003) incorporated an oil interceptor into a porous surface construction. Tests were carried out for worst-case scenarios such as the worst possible combined pollution and rainfall event to assess how the system retains pollutants within its structure. The results successfully demonstrated that this system can retain hydrocarbons, and can therefore offer outflow with improved water quality. However, where certain detergents are present in the pavement system, they can cause contamination of the outflow water, which may require secondary treatment to improve its water quality.

Metals

Heavy metals tend to be captured in the top layers of permeable pavements. One field analysis of material that clogged permeable pavements found high concentrations of cadmium, zinc, lead and copper. These concentrations appeared to be related to traffic intensity. Clogging materials with a finer particle distribution had the highest heavy metal concentrations (Colandini et al., 1995). Dierkes et al. (2002) observed that metal pollution concentrations within a permeable pavement parking lot decreased rapidly with depth. Most heavy metals were captured in the top 2 cm of the void space fill media. These results imply that through regular maintenance, where this top layer is removed and then refilled with new material, permeable pavements can remove heavy metals over long periods of time.

Studies have shown an improvement of water quality by filtration through PPS, which work well in removing suspended solids and particularly heavy metals from runoff. For example, Legret et al. (1996) showed that suspended solids and lead can be reduced by PPS up to 64% and 79%, respectively.

Kellems et al., 2003 showed that enhanced filtration using organic media was an effective alternative to chemical precipitation for the treatment of storm water. Filtration through a specific adsorbent organic medium can remove about 95% of dissolved copper and zinc.

In comparison to pavements made of asphalt, concentrations of zinc, copper and lead were significantly lower on permeable structures. Lead concentrations were in fact undetectable. A PPS should regularly be kept clean to prevent clogging.

Innovations And Future Research

In relation to porous pavements, honeycomb type shape modular made from polyvinyl chloride, PVC can be added to standard porous pavements systems. This usually improves the compressive strength of the porous pavement to allow for higher loads depending on the application and better infiltration.

The authors of this paper have recently worked to develop a honeycomb modular system, which can be installed within the sub-base of modern PPS and top layer as wearing layer together with 5mm gravel stones. The water gained from the below-ground pump can be used for many purposes. Natural water can be used to reuse water and subsequently reduce industrial and domestic water bills. The system is safe, reliable and efficient. The research focuses also on modelling the infiltration within permeable pavement using computer model, Flow-3D.

Further research on the short- and long-term effects of contaminants that remain in the PPS should be undertaken. The self-sustainability of these relatively new systems in comparison to traditional pavements requires further assessment. Moreover, the long-term impact of PPS on the environment is still unclear.

Finally, as PPS are becoming established as environmental friendly engineering techniques, there is a need for the development of simple computer-based decision support tools for engineers and planners.

Conclusions

This review paper summarised the diffuse literature on permeable and porous pavement systems. Permeable pavement systems (PPS) have become an important integral part of sustainable urban drainage systems despite the lack of corresponding high-quality research in comparison to other research areas. In contrast, porous pavements are usually associated with clogging problems and are therefore not as much applied in practise as PPS.

Design, maintenance and water quality control aspects relevant to the practitioner were outlined for permeable and porous pavement systems. The detailed design and specific maintenance requirements for PPS do not allow for the specification of general guidelines. Research is therefore likely to be empirical and of applied nature in the future.

The most important target pollutants were hydrocarbons, heavy metals and nutrients. The advantages and disadvantages of different PPS were discussed with the help of case studies concerning different water quality aspects.

Recent innovations were highlighted and explained, and their potential for further research work was outlined. The development of a combined water retention and soil improvement, water treatment and recycling pavement system is promising, and is therefore encouraged. Further work on the assessment of the self-sustainability and sustainability of PPS is also encouraged.

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