Analysis on Purification and Mechanism of Percolation Media to Pavement Runoff Pollutants

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Abstract

In order to make ecological percolation system play a superior role in the control of pavement runoff pollution, purification capacity of five typical percolation media was tested by laboratory simulating device, in which sewage sample was prepared equally to event mean concentration (EMC) of pavement runoff. Then, microscopic observation and element analysis are performed on percolation media using environmental scanning electron microscope and energy dispersive X-ray fluorescence spectrometer. Results indicated that purification effects of percolation media are significantly different. Percolation media mainly have two modes to reduce runoff pollutants concentration, pore adsorption and space interception, respectively. Finally, fuzzy comprehensive evaluation method was adopted to quantify purification effect of different percolation media. Combinations of percolation media were recommended for different pollution situations.

Keywords: percolation media, pavement runoff pollution, purification effect, microscopic mechanism.

1. Introduction

With deepening of urbanization process, the proportion of impervious surface increases rapidly, which leads sharp reduction of rainwater infiltration rate and great increase of total amount of urban runoff. A large amount of pollutants is contained in pavement runoff, especially in the initial runoff⁽¹⁻³⁾. Early research has shown that the concentration of pollutants in pavement runoff in Yangzhou city exceeds

the discharge requirements of surface-water seriously⁽⁴⁾. It will cause the deterioration of water quality and destruction of aquatic ecosystem if discharge into rivers or groundwater directly without purification treatment.

As a kind of source pavement runoff pollution control technology, ecological percolation system can improve the infiltration rate and reduce the concentration of runoff pollution. Besides it is efficient and low-cost⁽⁵⁻⁷⁾. It has received extensive attention of scholars all over the world in recent years. The core of percolation structure is percolation media. Volcanic, zeolite, diatomite and other mineral materials are widely used with many advantages, such as multi-hole, environmental protection, economy. But purification effect and mechanism of percolation media are different, which leads to the actual purification effect of percolation structure unevenly⁽⁸⁻⁹⁾. It is essential to study the purification ability and the blocking mechanism of percolation media.

In this study, runoff sample was prepared artificially according to the characteristics of road runoff pollution in Yangzhou. SS, COD, TP, TN, Zn, Pb are used to evaluate contamination degree of five typical mineral material. The combinations of percolation media with different runoff pollution conditions were recommended based on the analysis of decontamination effect of road runoff pollutants of different percolation media. Finally, the purification mechanism of the percolation medium was analyzed by means of microscopic test. The aim is to provide the basis for the practical application of the ecological percolation system in the control of runoff pollution

2. Test materials and test methods

2.1 Test materials

(a) Percolation medium materials

Percolation media used for ecological percolation structure should have stable performance, good adsorption, intercept performance, and will not release harmful material. Referencing filter material commonly used in water treatment, the following five kinds of environment mineral materials as the percolation media are selected by consulting commonly used filter on water treatment⁽¹⁰⁻¹²⁾. That is zeolite, slag, volcanic, ceramsite and diatomite. The main physical properties are shown in Table 1.

Table 1. Main physical properties of percolation media

	Zeolite	Slag	Volcanic	Ceramsite	Diatomite
Void content(%)	40	36	58	52	41
Volume-weight (g/cm ³)	1.35	2.20	1.21	0.77	1.11

(b) Test water sample

Existing literature data show that⁽¹³⁻¹⁴⁾, there is a big difference between water quality test results in different test locations and different number of rainfall. Some even are differences of orders of magnitude. Therefore, this test according to the existing research results⁽⁴⁾: The Event Mean Concentration of the typical runoff in Yangzhou. The concentration of the pollutants indicators and target are determined. The method of preparing test water sample is adding reagent in the water. Water sample by each target pollutant concentration and the amount of reagent adding are shown in Table 2.

Table 2. Target concentration of pollutant and reagent adding of 200L runoff

Reagent	Target concentration (mg/L)	Dose (g/200L)
SS Sedimentary soil	300	96.351
COD C ₆ H ₁₂ O ₆	250	53.49
TP KH ₂ PO ₄	1.5	1.104
TN NH ₄ Cl	10	8.45
Zn Zn(NO ₃) ₂	4	1.724
Pb Pb(NO ₃) ₂	0.4	0.688

(c) Test device

In order to measure the capacity of water storage and sewage interception of different percolation media, the experiment was carried out in the laboratory by simulation

device made by oneself. The design drawing is shown in figure 1. The device is composed of water tank, blender, self-priming pump, flowmeter, and water permeable device with inner diameter of 20cm, etc., It can not only carry out the simulated runoff pollution test, but also has the function of measuring the permeability coefficient of the material. There are four overflows on the water permeable device and the interval is 10cm, which can control the height of the water according to the thickness of the media.

Fig. 1. Test device design drawing

2.2 Test methods

Before the test, it is necessary to filter the media several times, and then need to be dried and cooled.

(a) The determination of water storage rate and permeability coefficient

The infiltration medium is evenly placed in the device with a thickness of 30cm which is the second overflow from top to bottom. The water outlet and overflow all closed at this time. 5L water is put into the device and 1h is set, then open the second overflow to collect water yield q_1 . The computational formula of water storage rate P is shown in Equation (1). The average value is adopted after repeated three times.

$$P = \frac{5-q_1}{3\pi} \times 100\% \quad (1)$$

After the percolation medium is in a saturated state, open the outlet and the first overflow, adjust the water flow of water tank to make the water in the overflow stream equably. The next, determine the water yield within 5min. Finally, calculate the permeability coefficient according to the Darcy's Law. The average value is adopted after repeated three times.

(b) purification test process

① Place the purification medium in the test device equably, the thickness is 30cm.

② Inject the water into the bucket, add the reagent to

water and stir fully for preparing the runoff.

③ Open the first overflow and the outlet of water permeable device. The sewage in the bucket is communicated with the water permeable device at the same time. Make the sewage flow uniformly in the overflow by adjusting the flowmeter. Collect water sample from the outlet after 3 min.

④ Determine the concentration of COD, SS, TP, TN, Pb, Zn in collecting water sample, the detection methods of pollutant concentration are shown in Table 3.

Table 3. Detection method of pollutant concentration

Pollutant index	Method
SS	Gravimetric
COD	Potassium dichromate
TN	UV-spectrophotometry
TP	Ammonium molybdate
Zn/Pb	Atomic absorption spectrophotometry

(c) Microcosmic test method

XL-30 Environmental Scanning Electron Microscope is used to observe the micro morphology of Percolation medium in the runoff sewage before and after the purification test. The contents of the elements in the percolation media before and after purification test are detected by energy dispersive X-ray fluorescence spectrometer⁽¹⁵⁻¹⁶⁾.

3. Results and discussion

3.1 Water storage rate and permeability coefficient

The percolation structure has excellent water storage capacity and infiltration capacity, and it is very effective in reducing runoff. The rainwater infiltrates into the ground through the percolation media and some or all of the surface runoff can be eliminated. But water storage capacity and penetration ability of different percolation media are different, so the water storage rate and permeability coefficient are determined in this paper. The results are shown in Table 4.

The water storage rates of the 5 kinds of percolation media are between 40~55% and all have good water storage capacity. Reservoir effect of Volcanic is the best, which is closely related to its large porosity and abundant pore structure. There is a certain correlation between the permeability coefficient and the porosity of the percolation media, the higher the porosity, the higher the permeability

coefficient.

Table 4. Water storage rate and permeability coefficient

	Zeolite	Slag	Volcanic	Ceramsite	Diatomite
Water storage rate (%)	42.6	40.8	55.1	50.7	51.5
Permeability coefficient (mm/min)	0.856	1.345	2.064	2.319	1.078

3.2 Results of percolation media' purification test

The results of percolation media' purification test are shown in Fig. 2. The removal efficiency of SS by 5 kinds of percolation medium is commendable, the removal rates are between 82%~92%. For COD and TN, the removal rates are between 30% ~50% and the difference is not significant. The TP purifying effect is poorer, removal rate from 15% to 40%. There are significant differences on the removal rate of heavy metals.

The removal effect of zeolite on heavy metals is better, and the removal rate reaches about 75%. In addition, the removal rate of Zn is obviously higher than that of other percolation media. The slag has great purifying effect on the various pollutants. The removal effect of volcanic on SS, TN, Pb is better, especially the purification effect of Pb is the most prominent, but the removal effect of TP is poorer. Ceramsite has outstanding removal efficiency of COD, SS, but the removal effect of Pb is very bad. Diatomite has better removal effect on TP, TN. The main reason for this distinction is that the composition, pore structure and pore distribution of materials are different, then lead to the different adsorption capacity and mechanism of different pollutants.

Fig. 2. Results of percolation media' purification experiment

3.3 Decontamination comprehensive evaluation and combination design of percolation media

The results of single percolation medium purification test show that the removal efficiency of different media for different pollutants was significant, and unable to directly evaluate the decontamination effect. On the other hand, there are great differences in the composition and concentration of pollutants in different road runoff. So the percolation media should be selected according to the requirements of the road pollution. Fuzzy Comprehensive Evaluation method, a comprehensive evaluation method, can be considered to judge the quality or state of something under the influence of multiple factors⁽¹⁷⁻¹⁸⁾. Therefore, this method is used to quantify the purification effect of the percolation media, so as to achieve the best purification effect.

Based on the results of previous researches, the runoff is divided into different types according to their dominant pollutants. It mainly includes 4 kinds: SS, COD runoff pollution, nutrient runoff pollution, heavy metal runoff pollution and integrated runoff pollution. The specific steps of FCE method are as follows:

① Object set : $X = \{x_1, x_2, x_3, x_4, x_5\} = \{\text{zeolite, slag, volcanic, ceramsite, diatomite}\}$.

② Factor set : $U = \{u_1, u_2, u_3, u_4, u_5, u_6\} = \{\text{SS, COD, TP, TN, Zn, Pb}\}$.

③ Mian weight vector : Based on the average density of the runoff of Yangzhou, proposed secondary pollution factor weight=0.05.

Main pollutant weights = $1 - \sum \text{Secondary pollutant weights}$

$$A_1 = \{0.40, 0.40, 0.05, 0.05, 0.05, 0.05\}$$

$$A_2 = \{0.05, 0.05, 0.40, 0.40, 0.05, 0.05\}$$

$$A_3 = \{0.05, 0.05, 0.05, 0.05, 0.40, 0.40\}$$

$$A_4 = \{0.17, 0.17, 0.17, 0.17, 0.16, 0.16\}$$

④ Determine the evaluation matrix (For the same pollutant, Purification efficiency normalization of different percolation media) :

$$R = \begin{bmatrix} 0.196 & 0.203 & 0.210 & 0.207 & 0.184 \\ 0.194 & 0.235 & 0.147 & 0.219 & 0.205 \\ 0.121 & 0.202 & 0.252 & 0.201 & 0.224 \\ 0.161 & 0.312 & 0.119 & 0.161 & 0.247 \\ 0.331 & 0.252 & 0.153 & 0.164 & 0.100 \\ 0.307 & 0.218 & 0.331 & 0.042 & 0.102 \end{bmatrix}$$

⑤ Fuzzy comprehensive evaluation set = $A \times R$, The calculation results are shown in Table 5.

Single percolation medium has a limitation on the removal of pollutants. Therefore, for the purpose of

achieving the best effect to the runoff pollutants removal, the combination of the percolation medium is more conducive. Based on the data obtained in Table 5, the combination forms of filtration media for different runoff pollution status are presented in Table 6.

Table 5. Results of purification ability by FCE

	Zeolite	Slag	Volcanic	Ceramsite	Diatomite
SS+COD	0.202	0.224	0.186	0.199	0.189
TP+TN	0.164	0.251	0.191	0.176	0.218
Zn+Pb	0.289	0.236	0.230	0.122	0.124
All	0.216	0.237	0.201	0.167	0.179

Table 6. Combination of percolation media

Dominant pollutants	Combining form
SS+COD	Zeolite + slag + ceramsite
Nutrient	Slag + diatomite
Heavy metal	Zeolite + slag
Integration	Zeolite + slag + volcanic

3.4 Microscopic mechanism analysis of percolation media

(a) Micro-Structure Analysis

XL-30ESEM is used to observe the microstructure of percolation media before and after the purification test, as shown in Fig.3.

The surface of the zeolite and diatomite presents tetrahedral network structure, which forms a good channel between materials. It is advantageous to the coordination between minerals and ions. Thus the purification of pollutants is mainly based on the mechanical interception of the gap between materials.

It can be observed from the image that the slag itself contains more porous vitreous, porous carbon and coke. These porous components have good adsorption effect on pollutants. It is clearly observed that Pollutants are adsorbed in the micropore. The surface of volcanic is uneven, with rich pore. It is clear that the inner pores are filled with pollutants after the purification test, so as to achieve the purification effect. Although the surface of the ceramsite is smooth to a certain degree, its interior has abundant pore. The main pollutants are adsorbed on hole wall, the porosity as well as volcanic will be populated with the passage of time. They are mainly through the internal pore adsorption to reduce runoff pollutants concentration.

Fig.3. The microstructure of percolation media before and after purification experiment

(b) Elemental analysis

It was found that none of percolation media contained N, P, Zn and Pb pollutant elements. Low pollutant content elements cannot be revealed because of the tiny scanning area. After the purification experiment, pollutant element content of percolation medium is shown in Table 7. The results indicated that zeolite mainly adsorbed Zn, Pb. Slag and ceramsite mainly has better adsorption effect on P and Zn. The adsorption effect of volcanic on N and Pb is better while diatomite mainly adsorbs N. They are consistent with the results of single percolation media' purification test.

Table 7. Weight of contaminant elements in percolation media (%)

	Zeolite	Slag	Volcanic	Ceramsite	Diatomite
N	\	\	52.48	\	100
P	\	14.52	\	27.14	\
Zn	43.2	85.48	\	72.86	\
Pb	56.8	\	47.52	\	\

4. Conclusions

In this paper, the purification effect of five kinds of percolation medium was investigated. The combination of percolation media with different runoff pollution conditions was proposed. The purification mechanism of the percolation medium was analyzed by means of microscopic test.

The water storage rates of the five kinds of percolation media are between 40~55%. It means that all have good water storage capacity. There is a certain correlation between the permeability coefficient and the porosity of the percolation medium, the higher the porosity, the higher the permeability coefficient. Purification effect of different percolation media are significant difference to discrepant road runoff. The removal effect of zeolite on heavy metals is better with the removal rate of about 75%. The slag has good purifying effect on the various pollutants. Volcanic is good at The removing SS, TN and Pb. Ceramsite has outstanding removal efficiency of COD and SS, but the removal of Pb is very bad. Diatomite has better removal effect on TP and TN. The fuzzy comprehensive evaluation method can be used to quantify the effect of different medium on the purification of pollutants. According to the results of the calculation, four kinds of percolation medium combination forms were presented in view of different runoff pollution conditions. Percolation media mainly have two modes to reduce runoff pollutants concentration which are internal pore adsorption and material space interception. Slag, volcanic and ceramsite reduce runoff pollutants concentration through internal pore adsorption prevailingly. While zeolite and diatomite mainly based on the mechanical interception of material gap.

In the follow-up studies, we should consider the effect of runoff pollution on purification after a long running time, particularly for the combination design of percolation media. And adding the factors, the influence of temperature on purification also needs to be taken into account.

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