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Rainwater quality assessment of a solidified soil cistern using new construction technology

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Abstract: A plastic mixture construction technology using MBER (material becoming earth into rock) soil stabilizer is introduced and the water quality of a solidified soil cistern using the technology is analyzed. Rainwater was harvested in July, 2012. Water quality of runoff and cistern water after storage was measured, including turbidity, chemical oxygen demand (COD), total nitrogen, nitrate, and ammonia. Results show that pollutant concentrations in runoff decreased with time, indicating that runoff in the early time should be removed. Nitrate concentrations in cistern water increased after storage, while the remaining parameters decreased. Measured pollutant concentrations did not exceed the limit according to the standard for drinking water in China. It can be concluded that the solidified soil cistern with plastic mixture construction technology can provide available water for domestic use.

Key words: soil stabilizer; cistern; construction technology; water quality

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With increasing demand of water resources, water shortage is becoming an important factor to restrict the economic development and ecological environment construction in arid and semi-arid areas, such as the Loess Plateau[1]. According to the Bulletin of First National Census for Water, there are nearly 60 thousand distributed water supply projects in China, and the beneficiary population reaches about 163×10^6 [2]. Rainwater utilization is an important kind of distributed water supply type, and it is proved to be a useful way to lessen water resources shortage[3-8].

Storage equipment is a core component for rainwater harvesting and utilization, and the common materials are red clay, cement mortar, concrete or plastic sheets and so on. However, the disadvantages of these materials are obvious, such as complicated application technology, high cost, poor durability, which have greatly limited the development of rainfall harvesting and utilization technology[9]. Therefore, an economical, efficient and environment-friendly cistern material and the corresponding technique are required. MBER[10] (a material becoming earth into rock) soil stabilizer is a new kind of building material and can significantly enhance the strength of soil and improve soil anti-seepage performance. The objectives of this research are to introduce a special construction technology using MBER soil stabilizer—plastic mixture construction technique. And then the cistern water quality is analyzed in comparison with harvested rainwater and runoff.

1 Material and Methods

1.1 MBER soil stabilizer and plastic solidified soil

MBER[10] soil stabilizer comprises of cementitious materials, alkaline catalysts, surfactant and slag, and so on. This material is a new kind of cheap and environment-friendly material, which can improve and enhance the mechanical property of soil and make soil into a stable and durable component through reacting with various types of soil. The solidified soil has the properties of resisting compression, impermeability and freeze proof by compacting and rolling after mixing with the soil and water according to a given proportion. Moreover, the MBER soil stabilizer can not only use the natural soil and local materials, which reduces the transport burden of sand and stone, but also use or deal with some common industrial wastes such as fly ash, coal rock, mine refuse, steel slag and other materials. Therefore, it has the advantages in economic and environmental protection.

According to the construction characteristics, the solidified soil can be divided into two categories, the dry hard

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solidified soil and the plastic solidified soil. MBER soil stabilizer and water are compounded to make the plastic solidified soil, and the plastic solidified soil has high moisture content and low buck density. Both mechanical and artificial methods can be used in the construction. The simple program of construction makes it easy to use in practice. Fan et al. [11-12] studied the physicochemical action and mechanism of stabilized soil, and gave a designing and molding technology for the construction of runoff-collecting area and cisterns with MBER soil stabilizer. Rainwater harvesting systems using MBER soil stabilizer have been effectively applied and popularized in the Loess Plateau at present.

1.2 Construction technology of plastic solidified soil cistern

Fan et al. [13] gave the construction technology and maintenance process of the plastic solidified soil cistern. Plastic mixture was made by soil, MBER soil stabilizer, water, fibre and etc. Water content is liquid limit, making the mixture in flow state. Fibre is used to avoid crack caused by dry shrinkage, and mesh fabric is used to improve tensile strength. Slurry seal technology is used to improve the durability.

The plastic solidified soil cistern has a good application prospect in the areas with good geological conditions of soil layer, and it also has a high strength and seepage performance. The details of the process are as follows: construction lofting—excavation—bottom rammer—soil sieving—adding soil stabilizer and fibre—making slurry—solidifying wall—adding mesh fabric—secondary consolidation—bottom treatment—maintenance—covering plate—earthing—adding handrail and water pipe.

The construction technology mainly includes the following steps:

1) Dug and make the cistern shape according to the requirements, and then make the inner surface rough.

2) Sieve the soil with 10 mm mesh screen, and soak soil to make slurry, then lay aside at least 24 h.

3) Stir the slurry to make it well-distributed.

4) Add fibre of 2.0 to 4.0 kg/m^3 and soil stabilizer of 100 to 200 kg/m^3 into the slurry. Mix and stir the mixture, and form fibre-solidified soil seriflux.

5) Spary the mixture of MBER soil stabilizer, soil, water and fibre to the surface, and tamper the mixture.

6) Add the mesh fabric to the surface, and fix it.

7) Solidify and tamper for the second time to make a structure which comprises of soil, solidified fiber soil, mesh fabric and solidified fiber soil.

8) Maintain the cistern wall and bottom about 2 d by sprinkling water. When the solidified soil has a certain strength, add 0.1 to 0.2 m^3 water and close the cistern inlet. Then keep on conserving for about 10 d.

1.3 Applications of plastic solidified soil cisterns

Two solidified soil cisterns have been built by the above method at the experimental base of the National Engineering Center of Water Saving Irrigation at Yangling and Dingbian in Shaanxi province, respectively. This construction technology combines the advantages of good water quality of clay cistern and high strength and good durability of concrete cistern. The infiltration index of the cistern is less than 10^{-8} cm/s and the service life is up to 15 to 20 years as that of the same as the concrete cistern. Moreover, the cost of this new kind of cistern with little environmental pollution is just cistern third of that of concrete cistern. The high strength and anti-seepage property can meet the requirements for durability and seepage, and the water quality is well at the same time[14-15]. This device is easy to be popularized in rural areas especially in the area without sand-gravel material such as the Loess Plateau, and has important practical significance for reducing water and soil loss and promoting the development of supplementary irrigation agriculture with harvesting rainfall in arid regions.

1.4 Samples collection and analysis

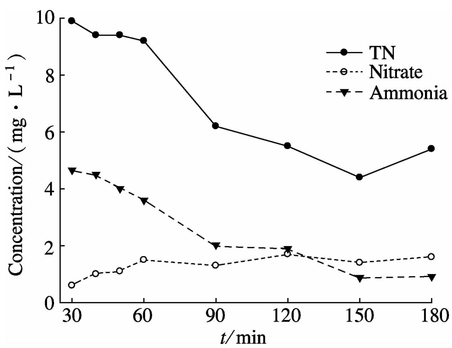
In order to further discuss the influence of the soil stabilizer, the cistern water quality at the experimental base of the National Engineering Center of Water Saving Irrigation at Yangling was tested. Rainwater was harvested on July 9, 2012, and both rainwater and runoff samples were collected. Cistern water was collected at 1, 2, 14, 24, 45 and 135 d after storage.

As the cistern water is mainly used for drinking water or farmland irrigation, the water quality assessment here is discussed based on the Standards for Drinking Water Quality (GB 5749—2006)[16]. According to the possible effect of soil stabilizer on the cellar water quality, turbidity, COD, total nitrogen, nitrate, and ammonia of the samples were measured. Turbidity was measured by HACH 2100P. The other parameters were measured by HACH DR2800, using the spectrophotometer method.

2 Results and Discussion

2.1 Assessment of runoff water quality

Runoff samples were collected between 30 and 180 min after rainfall. Temporal variations of pollutant concentrations are shown in Fig. 1. TN concentration (see Fig. 1(a)) was high at the beginning, and decreased rapidly from 9.9 to 5 mg/L at 180 min. The variation of nitrate (see Fig. 1(a)) concentration showed the same trend, and decreased from 4.66 to 1.0 mg/L. Unlike the two nitrogenous compounds, ammonia concentration (see Fig. 1(a)) increased from 0.6 to 1.6 mg/L. The initial runoff had a high turbidity (see Fig. 1(b)), which reached around 120 NTU. Turbidity decreased to 120 NTU at 120 min and 30 NTU at 180 min. COD could reflect the amount of organic pollution of water. COD concentration (see Fig. 1(c)) decreased rapidly from 23 to 7 mg/L during the first 60 min, and tended to be stable afterward. It is evident from this experiment that pollutants concentrations in the runoff decreased with time, and tended to be stable at latter time. The catchment-surface here was used as a courtyard, and the main source of pollution was outside substances, which were carried and dissolved into runoff. Therefore, the management of the catchment surface is of importance in practical application. First, the cleaning of the catchment surface should be done in order to decrease the source of pollution. Secondly, the initial runoff which contains a high amount of a pollutant should be removed according to particular situations.



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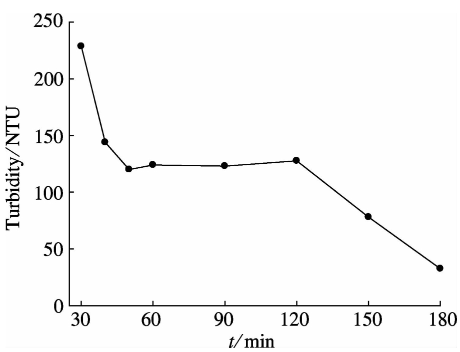

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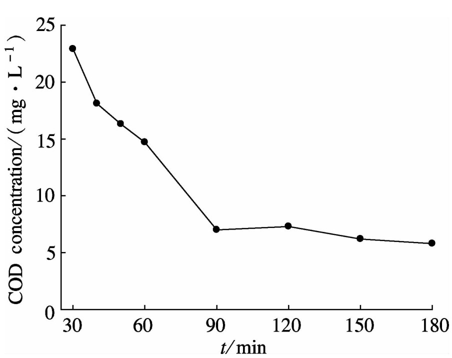

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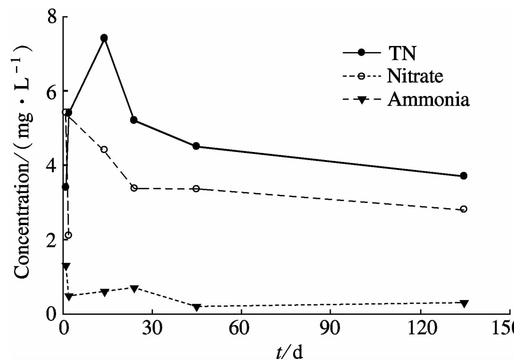
Fig. 1 Temporal variations of pollutants of runoff water samples. (a) TN, nitrate and ammonia concentrations; (b) Turbidity; (c) COD concentration

2.2 Assessment of cistern water quality

Cistern water samples after storage were measured and temporal variations of pollutants concentrations are shown in Fig. 2. TN concentration (see Fig. 2(a)) was 3.4 mg/L at the beginning, and increased to 7.4 mg/L on the 14th day, and then decreased gradually to 2.8 mg/L afterward. Nitrate concentration (see Fig. 2(a)) decreased from 5.4 to 3.5 mg/L. Ammonia concentration (see Fig. 2(a)) decreased from 1.3 to 0.3 mg/L. Water turbidity (see Fig. 2(b)) decreased from 91.4 to 31.5 NTU during the first 2 d, and decreased to 16 NTU on the 24th day, and 3 NTU on the 45th day. COD concentration (see Fig. 2(c)) was 14.7 mg/L at the beginning, and decreased to 7.4 mg/L on the 14th day, and increased to 10 mg/L on the 24th day, and decreased to be around 3 mg/L at last. The increase of COD concentration on the 24th day was due to the matter source and



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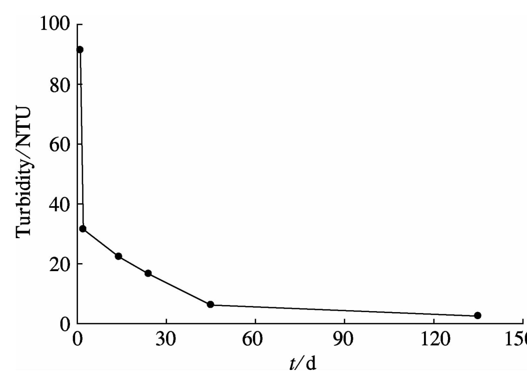

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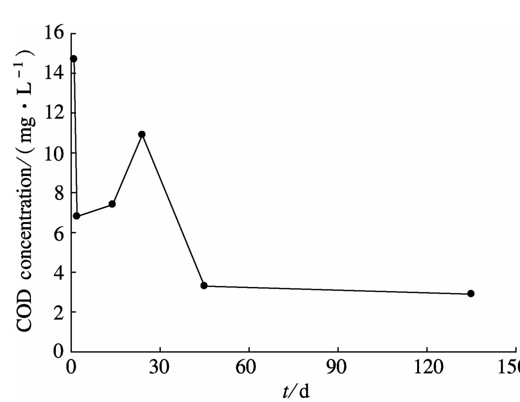

(c)

Fig. 2 Temporal variations of pollutants of cistern water samples. (a) TN, nitrate and ammonia concentrations; (b) Turbidity; (c) COD concentration decomposition process of organic matter. COD represents the status of organic pollution of the stored water, which was mainly caused by reducing substances. As the stored water was in a relatively closed environment, organic matter from water body and deposited material could produce the reducing substances, and then increase the COD concentration during the first days. The COD concentration increase in the stored rainwater was also reported by Zhao et al[15, 17].

It is evident from these results that pollutant concentrations in cistern water during storage tend to be decreased, which is due to the self-purification of the water body. The decrease of turbidity is due to sedimentation and flocculation, while the decrease of COD and nitrogen compounds is due to decomposition of organic matter by bacterium. Pollutants concentrations in cistern water after storage do not exceed the standard for drinking water of the distributed water supply, according to the Standards for Drinking Water Quality (GB 5749—2006).

2.3 Comparisons of water samples

To get an intuitive insight into the variations of pollutants of different water types in the process of rainwater harvesting and utilization, pollutant concentrations are compared among harvested rainwater, runoff and cistern water, and results are expressed by box and whisker plots (see Fig. 3). The boxes indicate the lower and upper quartiles and the central line is the median. The points at the ends of the "whiskers" are the 2.5% and 97.5% values. Turbidity (see Fig. 3(a)) and COD concentrations (see Fig. 3(b)) are in order of runoff > cistern water > rainwater. TN concentrations (see Fig. 3(c)) are in order of runoff > rainwater > cistern water. Ammonia concentrations (see Fig. 3(d)) are in order of rainwater > runoff > cistern water. Nitrate concentrations (see Fig. 3(e)) are in order of cistern water > runoff > rainwater. Pollutant concentrations in runoff are higher than those in rainwater to some extent. Pollutant (except nitrate) concentrations in cistern water are lower than those in runoff, which is due to the self-purification of the water body after storage. Nitrate is the final product of the nitrogen reaction, so the increase of nitrate concentration indicates the decomposition of nitrogenous compounds by bacterium.

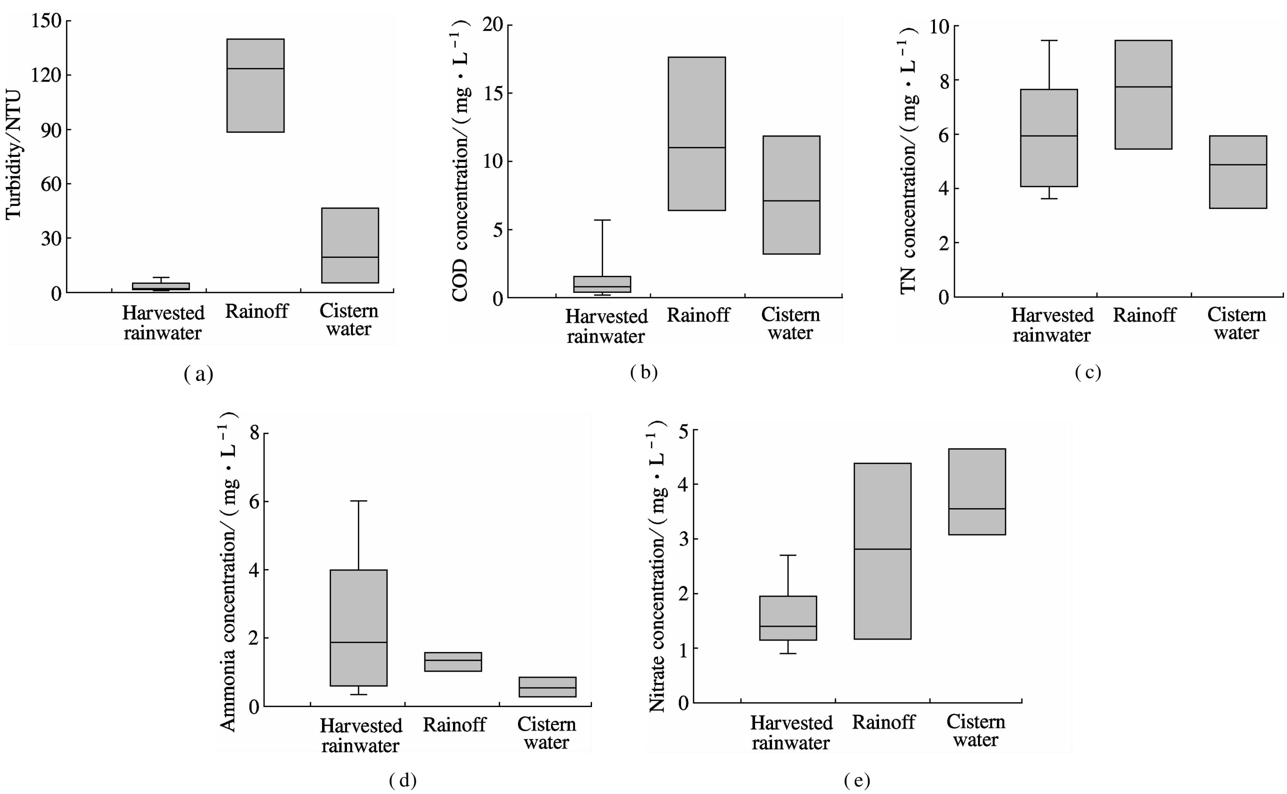

Fig. 3 Box and whisker plots for several water quality parameters of harvested rainwater, runoff and cistern water samples. (a) Turbidity; (b) COD concentration; (c) TN concentration; (d) Ammonia concentration; (e) Nitrate concentration

2.4 Relationship between turbidity and COD

The relationship between the turbidity and COD concentration of both runoff and cistern water samples is shown in Fig. 4. The result indicates that there is a significant correlation ($p = 0.001$) between the two parameters, which means that the higher the turbidity, the higher the COD concentration. This can be explained by the fact that the two parameters share the same matter resource. Turbidity is a measure of water clarity, and refers to how much the suspended solids in water decrease the passage of light through the water, and the suspended solids usually include soil particles (clay, silt and sand), algae, plankton, microbes, etc. While the organic matter in the water is mainly in an adsorption state, so turbidity and COD in runoff have the same matter source. During the storage, the sedimentation can decrease the amount of suspended solids, and hence decrease turbidity and COD concentration. This result is similar to the studies of Zhao et al [15]. Therefore, a decrease in turbidity often means a decrease in COD pollution, which is an important principle in purification and improvement of water quality in the process of rainwater harvesting and utilization.

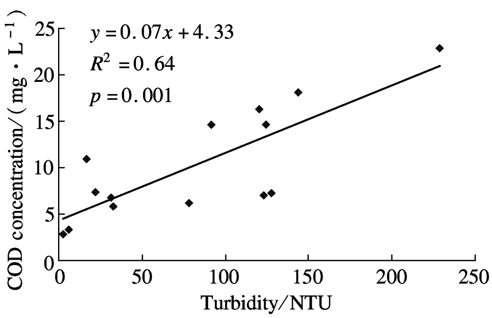

Fig. 4 Relationship between turbidity and COD concentration in runoff and cistern water samples

3 Conclusions

1) The water storage equipment made by tamping plastic solidified soil mixture with fibre and mesh fabric can be used as a cistern to collect and store rainwater. The mixture is made by mixing soil stabilizer and water according to a given proportion.

2) The turbidity, COD, total nitrogen, nitrate, and ammonia of water samples were measured. Pollutant concentrations in runoff decreased with time, indicating that runoff in the early time should be removed. Nitrate concentration in cistern water after storage increased, while the remaining decreased. A decrease in turbidity often means a decrease in COD concentration. Cistern water after storage can meet the standards for drinking water. It can be concluded that the solidified soil cistern with the plastic mixture construction technique can provide available water for domestic use from the point of view of water quality.

3) The plastic solidified soil cistern can make full use of local soil and water resources, and has the advantages of low cost and easy construction process compared with the traditional brick cement mortar cistern. So this device has wide application prospects and popularization value in water-scarce areas, especially in arid and semi-arid areas.

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一种新型施工工艺的土壤固化剂蓄水装置的贮存水体水质评价

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摘要:介绍了一种利用 MBER 土壤固化剂作为建筑材料的塑性施工工艺,并分析了利用该工艺施工的土壤固化剂蓄水装置的水体水质状况. 试验于 2012 年 7 月收集集流面径流,并进行后期贮存. 采集的集流面和窖水水样的监测指标包括浊度、COD、总氮、硝酸盐和氨氮. 结果表明,集流面径流中污染物含量呈现出随降雨历时增加而逐渐减小的变化趋势,因此降雨初期阶段的雨水应该弃用. 贮存窖水中硝酸盐浓度呈现随贮存时间增加而逐渐增大的变化趋势,而其余污染物浓度均呈现随贮存时间增加而逐渐减小的趋势. 上述指标的监测结果均未超过国家饮用水卫生安全标准. 研究表明该种装置可用于提供家庭用水.

关键词:土壤固化剂;蓄水装置;施工工艺;水质
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