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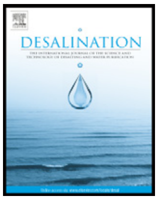

Salt removal from soil using the argil porous ceramic

Jalali Jalila [a,b], Balghouthi Moncef [a,*], Ezzaouia Hatem [a]

[a] Photovoltaic Laboratory LPV, Laboratory of Thermal Processes LPT, Research and Technology Center of Energy, Bordj Cedria CRTEn, Tunisia
[b] Bizerte Faculty of Sciences, Tunisia

HIGHLIGHTS

- Salt removal from soil using porous argil ceramic
- Saline solute movement in the soil and in the porous ceramic
- Evaporation, interaction between saline solution and porous ceramic
- Ionic salt interaction, germination and deposal on the top surface of the porous argil ceramic

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ABSTRACT

In this study, porous ceramic columns formed by argil of traditional pottery were used to remove salt from the saline soils. Experiences were conducted in a laboratory prototype to determine the salinity variation in different soil depths and locations as well as the salt germination and deposal on the porous ceramic. The obtained experimental results showed that this technique has effectively reduced the soil salt's concentration by 95%. Moreover, samples from the porous ceramic material were analyzed before and after application for the salt extraction from the soil. The analyses using the scanning electron microscopy (SEM) had showed the importance of the pore's dimensions and structures on the solution movement and salt deposal. In addition, the possible mechanisms of salt movement and deposal such as evaporation, interaction between saline solution and porous ceramic and salt ionic germination were discussed. Even a comparison with the Electrokinetic (EK) desalination method was performed to reveal the importance of using the porous ceramic column that constitutes a simple, cheap, preferment and appropriate environmental process.

1. Introduction

Water deficit limits the development of agriculture in countries with arid and semi-arid climates. The introduction of irrigation has enabled the development of a highly productive arable land in these areas, but its misuse caused negative effects on the quality of soils and waters [1, 2]. Secondary salinization is a serious threat to sustainable irrigated agricultural production as it is indicated that globally 20% of irrigated land is irritated by salinization, which is induced by the build-up of salts caused by irrigation [3]. This is the case of Tunisia, an arid and semi-arid Mediterranean country, in which soils affected by salts cover about 1.5 million hectares, i.e., around 10% of the whole territory area [4]. These saline soils are found throughout the country but especially in central and southern areas, where the inappropriate irrigation practices as well as the high evapo-transpiration rates are largely responsible for their extension.

Over the past decade, the treatment of the soil salinity has become a matter of interest for many researchers. In this context, several approaches have been used to ameliorate saline soils. Traditionally, the processes of subsoil crushing and draining using irrigation water have been applied to solve soil salinity problems. Soil drainage and reclamation is often achieved by soil leaching with fresh water. However, soil leaching is limited by land conditions and the availability of fresh water. For these reasons, a number of suitable technologies such as reverse osmosis and electrodialysis are available to provide desalinated water for agriculture [5,6]. These technologies are being commonly applied in a number of countries around the world. Wider application of technologies, especially for broader scale allocations, will only occur where there is limited availability of fit for purpose water for irrigation. But at a cost that is currently more expensive than that generally used for agricultural purposes. Therefore, it is not easy to completely remove salts from soil fields using these methods [7]. Electrokinetic (EK) restoration has successfully been used to control or remediate contaminated soils [7–10]. For this method, electrodes are installed in a soil field and an electrical gradient is applied across the electrodes. The contaminants are mainly transported by the electro-migration of the ionic species in

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[*] Corresponding author.

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the pore fluid toward the opposite electrode and by the electro-osmotic flow generated between the anode and the cathode [11]. However, the electrical energy consumption is a major barrier to the widespread application of the EK process for restoring saline soil; because it accounts for 10–15% of the total cost and 25% of the operating cost in the Electrokinetic remediation [12]. Among the various approaches used for saline soil amelioration, there is a promising method called the Evaporation Drainage Method (EDM). The concept of EDM is to remove excess salt through evaporation from fabric columns, called accelerators, installed in the soil taking advantage of the strong evaporation potential in arid and semi-arid climates [13]. The accelerators used in the experiments were of cylindrical shape made of highly absorptive cooking paper (Lion Corporation Ltd., Tokyo, Japan). The cooking paper is made of rolls of connected sheets having a dimension of 280 × 200 mm. Installing accelerators in saline water enhanced evaporation rate and removed salt through upward capillary flow and the subsequent salt precipitation on the surface of the accelerators. The efficiency of an accelerator in enhancing evaporation rate and salt removal is highly affected by its length and, to a lesser degree, its diameter. The evaporation rates are expected to increase with length logarithmically as long as the length of accelerator remains below the equilibrium capillary rise of the fabric. As accelerator length approaches the equilibrium capillary rise of the materials, the evaporation rate decreases accordingly. Increasing the length of accelerator from 60 to 300 mm increased the evaporation rate of saline solution from 3 to 10 mm/d and salt removal from 10 to 42% of the total salt in the solution. The EDM method permits the use of moderate salinity water for soil reclamation; since accelerators enhance the removal of salts from leached solution. The effectiveness of EDM in soil may be limited due to the difficulty of inserting the wicks in the soil profile and the need for long wicks to keep contact with the declining soil water level. At this juncture, suitable materials have to be used for the removal of salt from the soil. The materials used in this study are the porous ceramic columns formed by argil of traditional pottery (jarre).

Therefore, the objective of this paper is to examine the performances of the traditional porous ceramic as a tool for salt removal from saline soil. This treatment consisted in the application of the porous ceramic column to a soil contaminated by salts. The lower section of the column was vertically inserted into the soil, and the upper section remained above the soil surface. Indoor and outdoor experiences were conducted in a laboratory prototype to determine the salinity variation in different soil depths and locations as well as the salt germination and deposal on the porous ceramic. Besides, the analyses of SEM were performed to determine the morphologies of the used ceramic and the salt crystallization in the pores. In addition, the possible mechanisms of salt movement and deposal such as evaporation, interaction between saline solution and porous ceramic and salt ionic germination were discussed.

2. Materials and methods

2.1. Soil characteristics

Soil samples were analyzed to determine some properties of the soil used in the experiences. The distribution of the soil grains according to their sizes showed that the soil could be classified as fine sand. The principal hydrous characteristics are the following:

$$\theta_{cc} = 19.36\%, \theta_{pf} = 4.3\% \text{and} \, \theta_s = 40.2\%.$$

Where θ_{cc} is the volumetric water content at the field capacity, θ_{pf} the residual water content (the volumetric water content at the fading point) and θ_s the volumetric water content at saturation.

2.2. Method of obtaining ceramic columns and their properties

The used porous ceramic is one kind of the traditional ceramic pottery (Jarre). It is fabricated by mixing clay with other inorganic raw materials such as quartz and a combustible material (sawdust) and with a binder (water). The resulting homogenous mixture is then pressed using a mechanical press, or in some cases by manual molding using a pottery wheel, into the amphora shape. During sintering, the combustible material burns off and leaves behind pores. The micro- and nano-scale pores form complicated porous network. The geometry and surface properties of the pores are also the primary keys to the salt removal from soil. In the processing steps, sintering of the ceramic mass is fundamental to adjust several desired properties. The properties of the porous ceramic were illustrated in Table 1. In addition, rinsing operations of the ceramic column is a necessary step to dissolve salts which crystallize in the form of a layer along the pore walls and in form of hard crusts. Therefore, the ceramic column should be rinsed and regenerated by a simple washing using potable water. The column was left in a tank filled with water for 24 h. Then, the column was dried at ambient conditions during 24 h. The rinsing operation was repeated 2 times.

2.3. Experimental procedure

The study focuses on the importance of using the traditional porous ceramic for the salt extraction from the soil. Experiences were conducted in a laboratory prototype to determine the salinity variation in different soil depths and locations as well as the salt germination and deposal on the porous ceramic. Thus, two experiences were carried out: an indoor experience and an outdoor experience.

2.3.1. Indoor experiences

An amount of soil was placed in a parallelepiped container with a length of 75 cm, a width of 30 cm and a height of 40 cm. The base of the container was covered by a 5 cm thick gravel and 25 cm of soil. In order to make a uniform distribution of salt with a fixed quantity of salt in the container, the soil was wetted with a sodium chloride solution to obtain an initial solute concentration of 12g/l. This treatment consisted in the application of the porous ceramic column to a soil contaminated by salts. The lower section of the column was vertically inserted into the soil, and the upper section remained above the soil surface.

In order to circulate the air, we used a fan speed at 2.8 m/s located 30 cm above the column surface (Fig. 1). This treatment was determined by two tests with the same experimental conditions kept at two different ambient conditions. The first test was performed in the month January when the ambient temperature was low and the other was realized in June when the ambient temperature was important.

Four type-k thermocouples were used to measure the temperature of the soil at different locations and depths. The thermocouple readable of the soil surface temperature (0 cm) was covered by a 1 mm thin soil layer to avoid errors due to direct solar radiation exposure, and the other three thermocouples were inserted at depths of 8, 16 and 24 cm. They were designated as T4, T3, T2 and T7 respectively. Two thermocouples were used to read the temperature of the porous ceramic column. A thermocouple was placed on the upper face of the column (T5). The other is placed at the soil interface with the ceramic (T6). The temperatures were recorded each 10 min by a digital recorder.

2.3.2. Outdoor experiences

This experience was performed outside the laboratory. However, the used container is larger than the latter. This container was a parallelepiped 110 cm long, 90 cm wide and 40 cm high. The base of the container was covered by 30 cm of soil. It had initial solute concentration of 7 g/l. The experiences were effectuated in summer (hot season) under ambient conditions of temperature, relative humidity and air velocity. In addition, the thermocouples were inserted into the same sites of the indoor experiences. The aim of this test was to better understand how the desalination of soil by ceramic column works in order to improve the efficiency of such a treatment.