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# An Approaching the Thermal Resistivity Behavior for a Porous Media with Different Percentages of Gravels

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### *Author's contribution*

*The sole author designed, analyzed and interpreted and prepared the manuscript.*

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## ABSTRACT

**Aims:** To evaluate the influence of the coarse elements on the relationship between thermal and hydric soil properties.

**Study Design:** The samples were obtained from Camí de Can Solé (NE of Spain), and analyzed under laboratory conditions.

**Place and Duration of Study:** Department of Agri-Food Engineering and Biotechnology, Polytechnic University of Catalonia, between June 2011 and Setember 2011.

**Methodology:** Thermal conductivity was determined using thermal sensors of single needle. The experiments were carried out on monitorized soil columns where their water content and thermal properties were continuously recorded. Different percentages of gravels were added to the samples.

**Results and Conclusion:** A dataset related to water content and thermal resisitivity was gathered. The variability of the data depended on the coarse fragments. The relationship between thermal conductivity and water content show higher differences when the coarse elements were about 10% and 50%, being especially relevant to the position of the thermal sensor inside the soil samples.

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## 1. INTRODUCTION

A “soil coarse element” refers to all type of particle size that it is not able to be sieved by a sifter of 2000 μm of diameter. Usually, due to the soil genesis conditions we can find an abundance coarse materials in the soil profile. There are different works that make reference to the effects caused by these materials about the soil thermal properties for instance [1,2]. Some of these research studies make reference to the quantity and its relationship with the mass volume, to the size and the depth where these coarse elements are located [3]. Other effects induced by these elements are directly related with the soil porosity [4,5].

Some investigations carried out during the last decade, were focused on the dynamic of the thermal properties of the porous media with coarse elements, observing an anisotropy and heterogeneity in the media [6]. Higher coarse elements in soils used to present some problems in the experimental design, especially for installing sensors and probes to monitor the scenario, and not altering the soil structure.

[7] Suggest that the macroporosity in a consequence of the physical and chemical processes, and changes in the contact surface between fine and coarse particle size of the soil, as well. Therefore, the macroporosity will be a soil variable affecting to the soil phases liquid and gas [8,9] therefore the soil thermal properties, as well. Another aspect to take into account will be the influence of these fluxes on the correct development of the root system [10].

The aim of this research is to evaluate the influence of the coarse elements on the relationship between thermal and hydric soil properties.

## 2. MATERIALS AND METHODS

Samples were obtained from the top soil horizon (0-30 cm) of a plot located at Can Solé Road, in the delta plain of Llobregat River (Northeast of Spain). These soil samples were collected on one hand using a known volume core, and on the other hand were collected a quantity of disturbed soil at the same level. To characterize the soil the physical variables such as, particle size distribution, bulk density, total organic carbon content, and calcium carbonate content were measured. In addition, the residual water content (hygroscopic water) was determined. Particle-size distribution was determined using the wetting sieve method for 2000 to 500 μm, and a device by dispersion laser beams (Malvern Mastersizer/E) for particles smaller than 500 μm. Bulk density and total porosity were determined from undisturbed sample volumes. Total carbon content was analyzed by loss on ignition at 900ºC, and inorganic carbon content by loss on ignition at 200°C, both using a Shimadzu SSM-5000 A and solid sample module. These results allowed us to calculate both, total organic carbon content and calcium carbonate content. The residual water content was determined by loss in weight after drying the samples at 105ºC during 24 h.

Synthetic samples were developed using different percentages (10%, 20%, 30%, 40%, 50% and 80% $kg_{gravels}\cdot kg_{soil}^{-1}$ air dried) of coarse elements (25% $kg_{gravels}\cdot kg_{soil}^{-1}$ air dried of 2-4 mm and 75% $kg_{gravels}\cdot kg_{soil}^{-1}$ air dried of 4-8 mm). The samples were repacked into a specific soil column device.

Measurements of thermal-hydrodynamic properties were made on one soil column, constructed specifically for this experiment. Fig. 1, shows the column one, which was developed in polyvinyl chloride component.

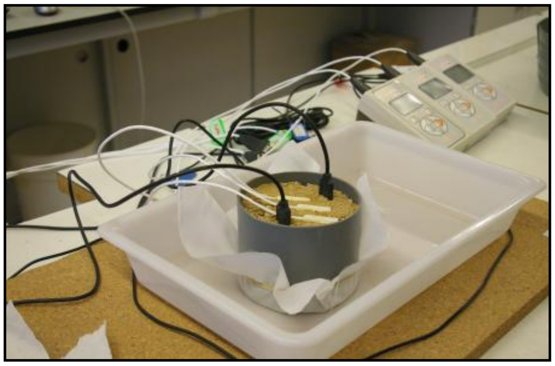

**Fig. 1. Top view of the soil column design with thermal sensors and moisture probes located**

Soil sample was repacked inside the cylinder and compacted to a target bulk density. The mean bulk density value was around 1.4 $g\cdot cm^{-3}$. This bulk density value was obtained through the known volume method, and it coincides with the values found in the literature e.g. [11,12]. To determine the thermal properties a single needle thermal sensor was employed, such as it is indicated in [13,14]. This kind of sensor uses the heat pulse methodology and yield reliable soil thermal resistivity (R) and the inverse thermal conductivity ($\lambda$) estimations, obtained by a non-linear least squares procedure during the process. The sensor was inserted in the middle of the soil sample.

The thermal data were collected using a KD2-Pro reader-logger. To determine the volumetric water content ($\theta$), the soil column was monitored with ECH2O EC-5 frequency domain probe (Decagon Devices Inc.). A Decagon Devices Em-5b data-logger was required to collect the water content and room temperature data. The column devices with repacked synthetic samples were placed during the experiment inside of an isothermal chamber to avoid the thermal drift.

## 3. RESULTS AND DISCUSSION

The studied soil from Can Solé Road was classified as silt loam textural class (USDA), with a particle size distribution for silt content always higher than 60%, mean sand content about 34%, and mean clay content about 4%. Mean bulk density was 1.47 g·cm-3 and total porosity 45%. Mean total organic carbon content was about 3.1% and mean calcium carbonate content was 40.3%.

Fig. 2, shows the plot of the thermal resistivity values obtained for a soil with different coarse elements content. The soil property thermal resistivity was chosen because it has a regular use in several applications such as are civil engineering such as underground power cables on wind mill stations or electric power stations, heat flux transfer in soils with permafrost for instance. Moreover, thermal resistivity is less dependent of the temperature than thermal conductivity.

The obtained values were found to be in the range of the values obtained by other authors as e.g. [15] for this textural class. In detail, for the same water content to correspond with the half average value in the field capacity water content [16], such as were found by [15,17]. The data shows divergences on the thermal resistivity values when the gravel percentage is about 10% $\text{weight}_{\text{gravels}}\cdot\text{weight}_{\text{sample}}^{-1}$. Obtained values for the same soil without gravels presented a mean thermal resistivity value close to 1.7 $\text{m}\cdot\text{K}\cdot\text{W}^{-1}$. When the gravel content increased, the thermal resistivity values increased, as well, presenting a higher value about 3.1 $\text{m}\cdot\text{K}\cdot\text{W}^{-1}$ for a gravel content of 10% $\text{weight}_{\text{gravels}}\cdot\text{weight}_{\text{sample}}^{-1}$. Following the experiment, i.e. increasing the gravel content in the soil sample, the values presented a linear decreasing behavior, showing a second thermal resistivity increase for 50% $\text{weight}_{\text{gravels}}\cdot\text{weight}_{\text{sample}}^{-1}$. The lowest thermal resistivity value was 1.3 $\text{m}\cdot\text{K}\cdot\text{W}^{-1}$ obtained for 80% $\text{weight}_{\text{gravels}}\cdot\text{weight}_{\text{sample}}^{-1}$.

The non-linearity in the thermal resistivity curve and its relationship with the several gravel content were related with the different variables related in the experiment. The large values of thermal resistivity for a sample with 10% $\text{weight}_{\text{gravels}}\cdot\text{weight}_{\text{sample}}^{-1}$, relate an increase of the porosity of the sample [18-20] due to the increase of the coarse elements, and the position of the thermal sensor inside the soil. This fact was particularly special, just that the vertical position increased the anisotropy of the system soil-gravels, which presented variations of the thermal property according to the position of the sensor inside of the sample.

On the other hand, the temperature of the sample and the isothermal chamber presented a negligible thermal oscillation, about 0.8 degrees Celsius, therefore the hydro-thermal equilibrium maintained in steady-state conditions, inside the soil column device. Several studies [21-23] have shown that in a wet soil around 10% to 20% of the heat was transferred in latent heat form cross to porous media. This factor, latent heat, presents high influence by the temperature, increasing a double value when the temperature increase 10 degrees Celsius [22]. Therefore, we can hold on that the variable temperature did not influence or lower the effects on the thermal resistivity.

On the contrary, the minimum thermal resistivity values are related with the higher gravels content (80% $\text{weight}_{\text{gravels}}\cdot \text{weight}_{\text{sample}}^{-1}$). In fact, this phenomenon can base it on the thin water film around the soil fine particles and coarse elements [11]. The liquid phase caused a sensor reading close to thermal resistivity of the film water ($R_{\text{water}}$= 1.5 $\text{m}\cdot\text{K}\cdot\text{W}^{-1}$), due to the increase of the macro-porosity for increasing the coarse fragments in the sample. In other words, the thickness of water film around the coarse elements could be actually higher than other scenarios with coarse particles in order to determine a reading close to water thermal resistivity. Furthermore, soil thermal conductivity is considered as the addition of the thermal conductivities of their components, therefore we can assume that the thermal conductivity value was the addition of liquid and solid phase (i.e. the own thermal conductivity of the coarse elements). In this case, the relationship could be an increase of the gas phase of the soil [24] involving a rising thermal resistivity values for this gravel content.

Fig. 3, shows the relationship between the thermal resistivity and water content for a soil with a gravel content about 35% $\text{weight}_{\text{gravels}} \cdot \text{weight}_{\text{sample}}^{-1}$. In this experiment two thermal sensors KS-1 was placed inside the soil column device. We chose two different positions respect to soil sample surface: Vertical (perpendicular to top sample surface) and horizontal (parallel to top sample surface).

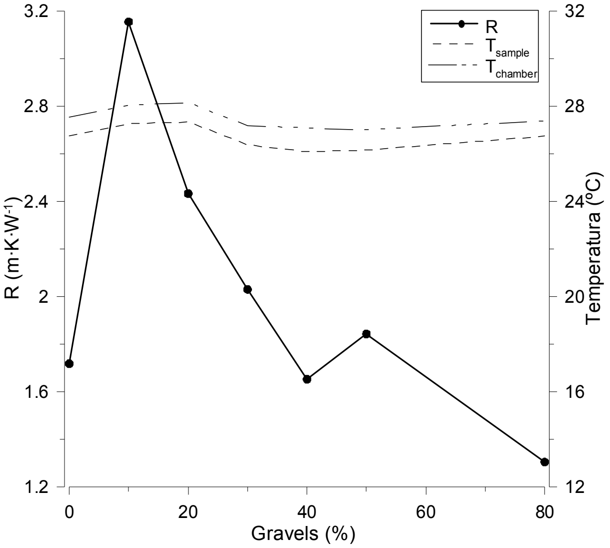

**Fig. 2. Relationship between thermal resistivity (R) and different gravel content for a silt loam soil. $T_{sample}$ = temperature of the sample; $T_{chamber}$ = temperature of the inner isothermal chamber**

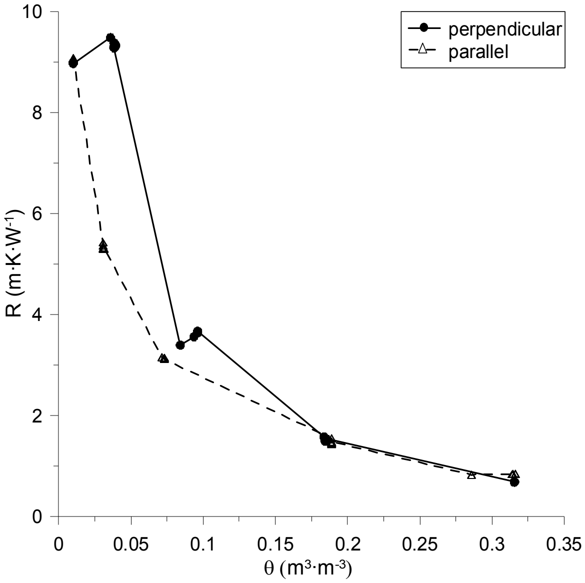

**Fig. 3. Relationship between thermal resistivity (R) and moisture (θ) for a porous media with gravels. Sensor insertion sample in vertical (perpendicular position to the surface of the sample), and in horizontal (parallel position to the surface of the sample)**

The results indicated the thermal sensor placed vertically shown divergences to integrate a volume of water and soil in depth, correctly. Monitoring the sample indicated that for the same water content value we obtained different thermal resistivity values as a function of the sensor positioning. The values were always higher for the vertical sensor. Both sensors coincide for the same value when the water content was about 20% vol·vol$^{-1}$. The differences are explained by the spatial interaction between the heat transfer and the sample moisture. Mostly important factors were the thickness and the geometry of the water film around the particles, when the water content was higher 15% vol·vol$^{-1}$. The sensor placed horizontally presented values where the water film was more homogeneous; meanwhile the vertical sensor distributed the heat pulse for several micro-scenarios, where the increasing and decreasing interactions of the liquid phase occurred, in contrast to the gas phase of the soil, presenting thus an increase of the thermal resistivity value.

On the whole of the experiment, the porosities less than 35% vol·vol$^{-1}$ (when air fraction was increased) presented a critical role respect to the thermal conductivity, because of the increment of the thermal resistivity [25] and a minor heat transfer inside the soil matrix.

## 4. CONCLUSION

To sum up, the soils with high coarse elements content present variability on the thermal and hydric dynamic, with both being well-related. High thermal properties variability was obtained in sample with 10% and 50% of coarse elements, for 3.15 and 1.84 m·K·W$^{-1}$, respectively.

On the other hand, for the same percentage of gravels the variability shown in the thermal and hydric dynamic was involved by the geometry and thickness of the water film around the particles. The position of the thermal sensor inside the sample presented divergences between vertical and horizontal location. The differences in the results were minimal for high water content and highest for scenarios whose water content was less than half average of field capacity water content for these types of soils.

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## COMPETING INTERESTS

Author has declared that no competing interests exist.

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