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Determination of the Temperature in Depth of Soil for the Region of Adrar. Effect of the Soil Nature

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Abstract

Considering the industrial and socioeconomic development that several developing countries, among which Algeria, are witnessing, the demand on the energy is ever growing. The conventional energies of fossil origin are very polluting and on the way of disappearing within some decades. Therefore, the recourse to the renewable energies is a good alternative because these energies are permanently available, very economic and environment friendly. One of these energies is the geothermic which consists in extracting calories stored in soil either for the production of the heating in the cold seasons or for the production of the cooling in the hot seasons.

The determination of the temperature of the depth of soil requires the knowledge of the kind of soil. As the latter is often taken by default, it is therefore important to study its influence on the temperature of the depth of soil as well as on the dephasing and the depth of penetration of the temperature signal.

In this context, we have conducted this study under the meteorological conditions of the Adrar town. The results achieved indicate that the yearly penetration depth as well as the dephasing are more influenced by the kind of soil whereas the average temperature of the soil surface is insensible.

Keywords: *Dephasing, Depth of penetration, Geothermic, Kind of soil, Temperature of soil.*

1. Introduction

The geothermal energy is the calorific energy stocked under the terrestrial surface. Depths of the earth conceal enormous quantities of natural heat, whose origin is especially from the disintegration of radioactive elements. According to the actual knowledge, the temperature culminates to 6000°C in the core of the earth and reaches about 1300°C in the superior coat of the terrestrial globe. The geothermal flux that arrives to the surface of the globe passes 40 billions of kW. More than 99% of the mass of our earth are submitted to temperatures passing 100°C. Only 0.1% are colder than 100°C. On the average, the temperature increases about 3°C by 100 meters of depth from the surface of the soil, what corresponds to a normal geothermal gradient.

The geothermic is a renewable energy. It consists in extracting calories stocked in soil for the production of electricity (geothermic high temperature) or of the heating (geothermic low temperature).

On the other hand, seeing that the temperature of soil from a given depth is quasi-constant during all year, so this same temperature can have two different applications. With an adequate exchanger air-soil, we can exploit this heat for the production of the heating during the cold seasons and for the production of cooling during the hot seasons. Thus, we can cover a good part of the energizing needs of heating and cooling. The cost that intervenes in the realization of a geothermal installation and which can appear high is compensated if we imagine that for a long period, we will produce heating and cooling with a free energy and our invoice of electricity will be considerably reduced.

Besides, the knowledge of the geothermal stratum is a factor more that necessary for the construction of the geothermal installation. It is important to evaluate beforehand the geothermal potential of the region to study. The temperature of soil depends on the depth and on the meteorological conditions of the site as the solar irradiation, the ambient temperature and the speed of wind. It also depends on the kind of soil and the surrounding medium of the site as for example the presence of a building to the neighborhood.

Because of the unavailability of all experimental data of Adrar region notably those that concern the kind of soil, we have prepared this paper in order to examine the influence of this parameter on the temperature in depth of soil.

2. Theoretical modeling

2.1 Modeling of the temperature in depth of soil

The soil is assimilated to a homogeneous semi-infinite medium whose physical properties are constant and independent of the depth z, and that is submitted to a sinusoidal signal (the temperature in the surface of soil, T_{soil}).

In this model, the temperature in the surface of soil is a sinusoid given by the following equation:

$$T_{surf}(t)=\overline{T}_{surf}+\sum_{j=1}^{N}A_{surf}(j)\sin\left(w(j)\times t-\varphi_{surf}(j)\right) \quad (1)$$

N being the number of harmonic and (j) is a positive integer number going from 1 to N.

We lean on the model of the semi-infinite medium, we can deduct the temperature of soil at a given depth z and a time t:

$$T_{soil}(z,t)=\overline{T}_{surf}+\sum_{j=1}^{N}A_{surf}(j)\times\exp\left(-\frac{z}{\delta[w(j)]}\right)\times\sin\left(w(j)\times t-\varphi_{surf}(j)-\frac{z}{\delta[w(j)]}\right)+geo\times z \quad (2)$$

The depth of penetration for a signal temperature of pulsation w(j) is given as a function of the thermal diffusivity of the soil by the following relation:

$$\delta[w(j)]=\sqrt{\frac{2\times\alpha_{soil}}{w(j)}} \quad (3)$$

We can calculate the pulsation w(j) from the following equation:

$$w(j)=\frac{2\times\pi}{P}\times j \quad (4)$$

P: indicates the period of the signal, it is expressed in seconds and it spreads on one whole year.

The coefficient geo is the gradient of temperature due to the geothermal flux. This flux is considered to be uniform at every point of soil and it directs vertically upwards. The geothermal gradient is taken, by default, equal to 0.03 °C.m-1. However, if the depth is weak, the effect of the geothermal gradient can be disregarded.

2.2 Modeling of the temperature in the surface of soil

For lack of the experimental data for the temperature of the soil surface, we have used a model based on the energizing balance of the soil surface in view to deduct an expression for its temperature. This balance is established of the following manner:

The surface of soil receives a quantity of energy from the sun as an irradiation and from the environment as a sensitive convective heat due to the wind. In return, it loses by latent convective heat to environment and by irradiation and conduction in exchange with sky and soil respectively. That can be translated in equation as follows:

$$Q_{cond}=(Q_{r\_solar}-Q_{r\_soil,sky})+(Q_{conv\_sensitive}-Q_{conv\_latent}) \quad (5)$$

Q_{cond} is the heat flux transmitted by conduction in soil. It is determined by the following relation:

$$Q_{cond}=\lambda_{soil}\left.\frac{dT_{surf}}{dt}\right|_{z=0} \quad (6)$$

The parameter λ_{soil} is the coefficient of thermal conduction of soil.

Q_{r_solar} is the quantity of the solar irradiation absorbed by the surface of soil, it is evaluated by the following relation:

$$Q_{r\_solar}=(1-\rho_{soil})\times G \quad (7)$$

$Q_{r\_soil,sky}$ is the heat flux exchanged by radiation between the surface of soil and the sky, it is given by the following equation:

$$Q_{r\_soil,sky}=\varepsilon_{soil}\times\sigma\times\left(T_{surf}^{4}-T_{sky}^{4}\right) \quad (8)$$

Where ε_{soil} and σ are respectively the emissivity of soil and the constant of Stefan-Boltzman.

$Q_{conv\_sensitive}$ is the heat flux due to the convection of wind, it is estimated by the following relation:

$$Q_{conv\_sensitive}=h_{wind}\times\left(T_{a}-T_{surf}\right) \quad (9)$$

With:

$$h_{wind} = 0.5 + 1.2\sqrt{V_{wind}} \quad (10)$$

Q_{conv_latent} is the latent heat flux due to the evaporation at the soil surface, it is evaluated by the following empirical relation:

$$Q_{conv\_latent} = c_{lat} \times f \times h_{wind} \times \left[\left(a_{lat} \times T_{surf} + b_{lat}\right) - HR \times \left(a_{lat} \times T_a + b_{lat}\right) \right] \quad (11)$$

HR being the relative humidity of air. The empirical constants are defined as follows:

a_{lat} =103 [PaK^{-1}] (12-a)

b_{lat}=609 [Pa] (12-b)

c_{lat}=0.0168 [K.Pa-1] (12-c)

The empirical parameter f depends on the kind of soil and degree of soil humidity:

TABLE 1. Variation of the parameter (f) according to the content in water of soil.

Kind of soil	Factor f
Arid	0.1 - 0.2
Dry	0.4 - 0.5
Humid	0.6 - 0.8
Saturated	1

We introduce a new coefficient of exchange equivalent designated by h_{eq} which includes the heat flux lost in exchange with the sky and the one that the surface of soil receives in exchange by convection with the ambient air:

$$Q_{conv\_sensitive} - Q_{r\_soil,sky} = h_{eq} \times \left(T_a - T_{surf}\right) \quad (13)$$

2.3 Transformation in series of Fourier

The monthly averages of ambient and horizontal solar irradiation of the town of Adrar are presented in the *Table (2)*. These data are transformed in harmonic series of Fourier as follows:

$$T_a(t) = \overline{T}_a + \sum_{j=1}^{N} A_T(j) \times \sin\left(w(j) \times t - \varphi_T(j)\right) \quad (14)$$

$$G(t) = \overline{G} + \sum_{j=1}^{N} A_G(j) \times \sin\left(w(j) \times t - \varphi_G(j)\right) \quad (15)$$

T_a and G designate the ambient temperature and the solar irradiation respectively. N indicates the number of harmonic. In this steady, we take N equal to 5.

We have injected these last two expressions in the balance of energy and after we have made the necessary simplifications, we led to what follows:

$$\overline{T}_{surf} = \frac{\left(1 - \rho_{soil}\right) \times \overline{G} + h_r \times \overline{T}_a + \left(h_r - h_e\right) \times \frac{b_{lat}}{a_{lat}}}{h_e} \quad (16)$$

$$tg\left(\varphi_{surf}(j)\right) = \frac{\left(h_{cond}(w(j)) + h_e\right) \times Y_2(j) - h_{cond}(w(j)) \times Y_1(j)}{-\left(h_{cond}(w(j)) + h_e\right) \times Y_1(j) - h_{cond}(w(j)) \times Y_2(j)} \quad (17a)$$

$$A_{surf}(j) = \frac{Y_1(j) \times \sin\left(\varphi_{surf}(j)\right) + Y_2(j) \times \cos\left(\varphi_{surf}(j)\right)}{h_{cond}(j)} \quad (17b)$$

With:

$$h_e = h_{eq} + h_{wind} \times a_{lat} \times c_{lat} \times f \quad (18a)$$

$$h_r = h_{eq} + h_{wind} \times a_{lat} \times c_{lat} \times f \times HR \quad (18b)$$

$$h_{cond}\left(w(j)\right) = \frac{\lambda_{soil}}{\delta\left[w(j)\right]} \quad (18c)$$

$$Y_1(j) = \left(1 - \rho_{soil}\right) \times A_G(j) \times \cos\left(\varphi_G(j)\right) + h_r \times A_T(j) \times \cos\left(\varphi_T(j)\right) \quad (18d)$$

$$Y_2(j) = -\left(1 - \rho_{soil}\right) \times A_G(j) \times \sin\left(\varphi_G(j)\right) - h_r \times A_T(j) \times \sin\left(\varphi_T(j)\right) \quad (18e)$$

3. Results & discussion

The town of Adrar is situated in the Southwest of Algeria. Its site is characterized by an altitude of 264m over the sea, a longitude of 0.17°W, a latitude of 27.53°N and a reflectance of 35%. The length of the day maximum corresponds to the solstice of summer is 13H 46mn while the length of the day minimum corresponds to the solstice of winter is 10H 14mn.

Considering the unavailability of the hourly data of one whole year for the town of Adrar, we have used the illustrated monthly averages in *Table (2)*. The data of ambient temperature are the results of ten years of expe-

TABLE 2. Illustration of the meteorological data for the town of Adar.

Month	Average ambient temperature (°C)	Average hourly solar irradiation (Wh/m²)
January	12,1	361,67
February	15,4	445,5
March	19,6	561,67
April	24,3	639,67
May	28,4	661,17
June	34,4	683,5
July	36,5	675,08
August	36	626
September	31,8	548,83
October	24,5	454,17
November	17,2	369,17
December	13,2	327,67

rience (1974-1984), what gives them a big reliability (Station weather report of Adrar). Concerning the data of the solar irradiation, we have extracted them from the SOLAR ATLAS OF ALGERIA, volume 2.

In order to study the influence of the kind of soil and the period of the signal of temperature on the depth of penetration, we took as a period of signal: one day, one week, one month and one year. We chose three kinds of soil as it is indicated in ***Table (3)***:

TABLE 3. Kind of soils and their physical and thermal properties.

Kind of soil	Density (kg/m³)	Thermal diffusivity (m²/s)	Thermal Capacity (J kg/°C)
Clay	1500	9.69 x 10-7	880
Silt	1800	6.22×10^{-7}	1340
Sand	1780	3.76×10^{-7}	1390

Results presented on ***Figure (1)*** show two things. Firstly, we observe that the depth of penetration corresponding to a period of one year passes the three meters (3m) for the clay but it is lower by two meters (2m) from the sand. It means that a soil in clay presents a big sensitivity to the yearly climatic variations in comparison with a sandy soil. It follows that the study of the soil is very essential for the determination of the temperature in depth of soil.

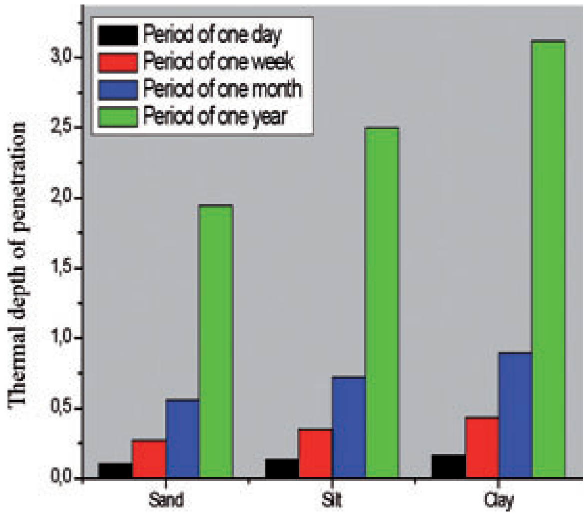

Figure 1. *The thermal depth of penetration according to the kind of soil.*

Secondly, for the three kind of soil, the depth of penetration corresponding to a monthly period is lower by 1m. This last result brings us to say that as the monthly climatic variations are only felt little by a layer deep of the terrestrial crust, we can use the monthly averages of the ambient temperature and the solar irradiation to calculate the temperature of soil for a given depth without fearing that it has big effects on the accurateness of our results.

Besides, the kind of soil doesn't seems to have an effect on the average temperature of the soil surface (***Figure 2***) whereas it has a remarkable influence on the dephasing (***Figure 3***). For example, for a depth of 3m, the dephasing is of 90 days for the sand while it is less than 60 days for the clay. It is shown that the dephasing is inversely proportional to the yearly penetration depth. In other words, the more this one is big the more the dephasing is small.

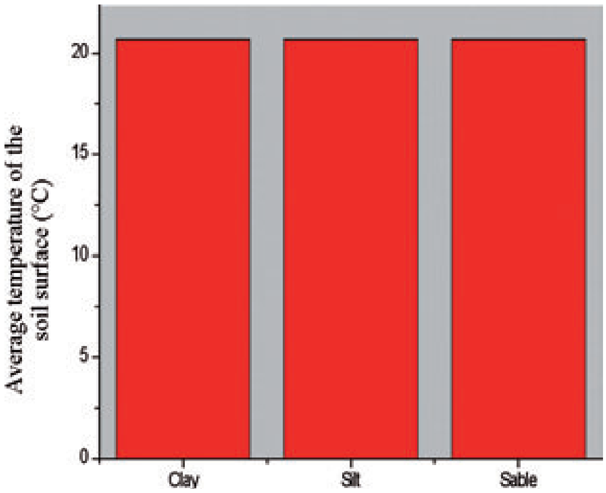

Figure 2. *Representation of the average temperature of the soil surface according to the kind of soil.*

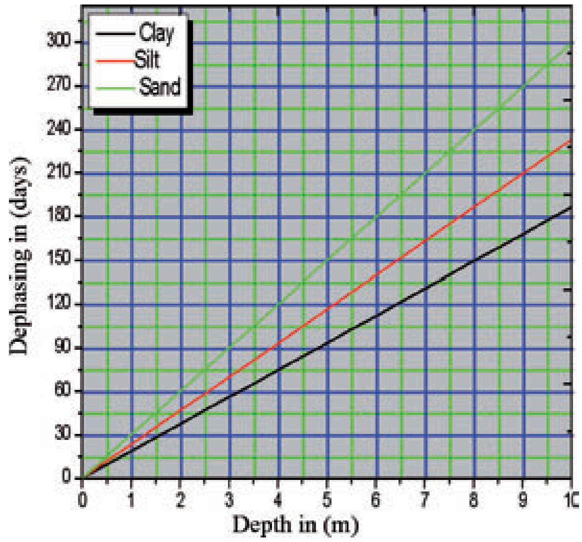

Figure 3. *Variation of the dephasing according to the depth in the soil.*

As for the evolution of the dephasing according to the depth, the illustrated results in the ***Figure 3*** indicate that the more one penetrates in soil the more important the dephasing becomes. In order to make the results independent from the kind of soil, we have taken as unit of length in the ***Figure 4*** the yearly penetration depth. The evolution of the soil temperature during one year according to the depth in soil shows that the amplitude of the temperature signal decreases when the depth increases and beyond of a distance being worth two times the depth of penetration, the temperature of soil doesn't have the shape of a sinusoid and it has a constant value.

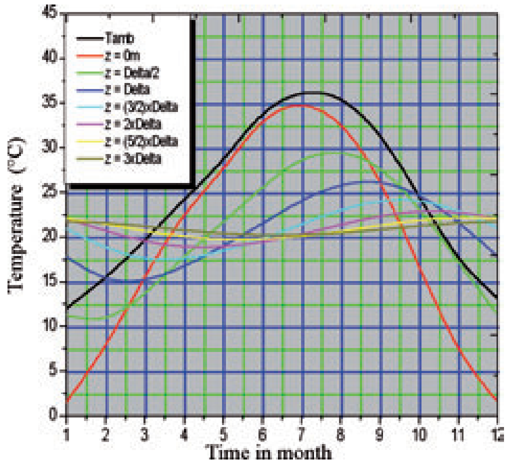

Figure 4. *Temperature in the depth of soil.*

Conclusion

In this work, we have studied the influence of the kind of soil on the temperature in depth of soil for the town of Adrar. The results indicate that this parameter which is often taken by default has an important influence on the yearly penetration depth and on the dephasing. For the clay we have found that the yearly penetration depth passes the three meters (3m) while it is hardly equal to two meters (2m) for the sand.

Besides, for a depth of 3m, the dephasing is three months for the sand whereas it is less than two months for the clay. It is shown also that a temperature of soil understood between 17°C and 24 °CS is obtained for a depth z = (3/2) x δ. This last depth corresponds to a distance of 2,90m in the sandy soil and 4,60m in the clayey soil. The difference is about 1,7m.

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Nomenclature

Latin symbols:

A	:	Amplitude
h	:	coefficient of thermal heat transfer ($W/m^2.K$)
P	:	Period (s)
V	:	Wind speed (m/s)
z	:	Distance (m)
G	:	Horizontal solar irradiation (W/m^2)
HR	:	Relative humidity of air
T	:	Temperature (K°)
t	:	time
Q_{cond}	:	Flux of heat conduction (W/m^2)
Q_{r_solair}	:	Flux due to solar irradiation (W/m^2)
$Q_{r\_soil,sky}$	:	Flux of heat exchanged between the soil and sky (W/m^2)
$Q_{conv\_sensitive}$	:	Flux of sensitive heat exchanged by convection (W/m^2)
Q_{conv_latent}	:	Flux of latent heat exchanged by convection due to the evaporation (W/m^2)
geo	:	Geothermal Gradient (°C/m)
w	:	Pulsation (rad/s)
N	:	Number of harmonics
$\overline{T}$	:	The average temperature (K)
$\overline{G}$	:	The average solar irradiation (W/m^2)

Greek symbols:

α	:	Thermal diffusivity (m^2/s)
λ	:	Thermal conductivity (W/m.K)
φ	:	Initial phase (rad)
ε	:	Emissivity
ρ	:	Reflectance
σ	:	Stefan-Boltzmann constant ($W/m^2.K^4$)
δ	:	Depth of penetration (m)

Index:

a	:	Ambient
G	:	Global solar irradiation
T	:	Temperature
surf	:	Surface
cond	:	Conduction