Evaluation of the Thermal Resistance of Certain Earth Crust Layers Based on Petrophysical Properties Obtained from Laboratory Analysis of Drilling Samples

TUDORA CRISTESCU*, EUGEN VASILIU
Petroleum-Gas University of Ploieşti, Drilling, Extraction and Transport of Hydrocarbons Department, 39 Bucureşti Blvd., 100 680, Ploieşti, România

This study presents a model for the calculation of the thermal resistance of a crust layer, which have been applied for an area of Romania. Appropriate cores were collected, following geologic exploration, carried out by a specialized firm. Petrophysical properties of the samples were obtained from measurements made in an approved laboratory.

Keywords: layers of the Earth's crust, thermal resistance, geophysical measurements.

The question of what is inside the Earth crust has been a fascinating pursuit. Evaluation of physical properties of the crust layer is not only of scientific, but also of practical interest . Both the choice of location for industrial plants or construction of buildings as well as of the method of exploitation from deposits of useful substances, require knowledge of the geophysical properties (such as composition, porosity, and fluid saturation) and thermal properties of the crust.

An original model is proposed to assess the thermal resistance of layers of the crust, which uses known geophysical and thermal properties of geological strata. The thermal resistance to the transfer of heat by conduction through a flat wall, R'_t, measured in [K/W], is expressed as [2]:

$$R_t^{'} = \frac{\delta}{\lambda A} \qquad (1)$$

When the area is $A = 1\text{m}^2$, the thermal resistance of a stratum R_t, measured in [m^2K/W], is expressed as:

$$R_t = \frac{\delta}{\lambda} \qquad (2)$$

We evaluate the equivalent thermal conductivity of a fluid-saturated porous medium by applying the weighed geometric mean model [1, 3-5]:

$$\lambda = \lambda_f^{\phi} \cdot \lambda_S^{1-\phi} \qquad (3)$$

The thermal conductivity of the solid is calculated as a weighed average according to its volumetric composition and thermal conductivity of the components:

$$\lambda_S = \sum_{i=1}^{4} r_i \lambda_{S,i} = r_1\lambda_1 + r_2\lambda_2 + r_3\lambda_3 + r_4\lambda_4 \qquad (4)$$

In relation 4 the notation for solid components is as follows: 1 - clay, 2 - dust, 3 - sand, 4 - gravel, r_i- volume fraction of solid component *i* and $\lambda_{S,i}$ - thermal conductivity of solid component *i*, [W/mK].

For a fluid consisting of water and air that saturates a porous medium, the thermal conductivity is calculated as a weighed average based on the thermal conductivity of the fluid components and their saturation:

$$\lambda_f = S_{aer}\lambda_{aer} + S_{apa}\lambda_{apa} \qquad (5)$$

Experimental part

The application of the original model presented above requires knowledge of the geological layers characteristics. The geotechnical study should involve following steps:

- general geological mapping;
- geological drilling;
- delineation and characterization of geological strata;
- sampling;
- analysis of samples in an authorized laboratory;
- selecting the necessary petrophysical properties for evaluating the thermal resistance.

Note that these steps require dedicated exploration costs, time spent on organizing and carrying out the work, qualified staff, specific machines and authorized equipment.

A specialized firm conducted a geotechnical study in a project involving the construction of an industrial objective. To this end, a general geological mapping and geotechnical drillings were performed. A perimeter located in the Romanian Plain was investigated. Geotechnical drillings were performed with mechanical drills GTR 790 RHB. We have executed a number of PDUs (dynamic light penetration).

Following geotechnical boreholes and cores observation we established the lithological sequence and have described the existing landfill on the site. Tables 1…5 contain such characterizations corresponding to five geotechnical explorations, denoted by F1 ... F5. Samples, undisturbed, were analyzed by an approved laboratory.

Table 6 presents the results of laboratory measurements on samples from geotechnical boreholes. Samples corresponding to each geologic exploration were marked with F1 ... F5 based on the geological drill, to which we added the number corresponding to the lithologic layer analyzed. Thus, the resulting notation was, for example, F11, F12. Thermal resistance was measured for horizons located at depths of 0.6 m to about 2.4 - 3.4 m We did not analyze the first layer placed at 0 - 0.6 m, which corresponds to the topsoil, and the 0.6 - 2.2 m layer, which corresponds to horizon transition, because these layers are stripped in a building project. Also, we did not study layers with a depth greater than about 3.4 m since the building foundation, in

---

* *email: tcristescu@upg-ploiesti.ro*

general, does not exceed the depth. In table 6, the composition particle size of the solid components is 1 - clay, 0.005, 2 - powder of 005 ... 0.05, 3 - sand of 0.05 ... 2, 4 - gravel with the grain greater than 2.

Obviously, if necessary, a study similar to the one described in this work can be extended to higher layers of depth if the following conditions are satisfied: there is an adequate geotechnical study, samples are taken from each layer, and laboratory tests are carried out in order to find the petrophysical properties of these samples.

Results and discussions

After analyzing, selecting and interpreting the laboratory results and knowledge of the studied lithologic layer characteristics, we applied the original calculation model to calculate the thermal resistance of a layer of crust.

Table 7 presents the results of calculations performed by applying relations (2) - (5). The thermal resistance, expressed in [m^2K/W], is directly proportional to the thickness and inversely proportional to the equivalent geological thermal conductivity of the stratum. The thickness is known from measurements that are carried out during geologic exploration, and strictly depends on the individual case. In the cases we investigated the lithologic layer is modeled as a porous medium saturated with fluid. Solids and fluids that make up a porous medium, porosity, composition solids, saturation, fluid nature of each component, are all factors that require calculation for each particular case of a transport property, in this case, the calculation of the heat transport. It should be mentioned that these properties are not constant even within the same stratum. Such an environment is characterized by a thermal conductivity equivalent. From the above it follows that each layer has its properties to be determined by taking samples "in situ" and authorized laboratory analysis. Equivalent thermal conductivity values obtained after applying the proposed original model were compared with relatively similar data available in specific publications [1, 3, 5], taking into account the many factors that influence this heat transport property. The comparison led to acceptable concordances; this concordance needs to be again emphasized given that each analyzed case has specific particular characteristics; each fluid-saturated porous medium, especially the ones related to terrestrial strata, are unique because transport properties such as thermal conductivity depend on many factors.

Conclusions

- The original calculation model proposed in this work to assess the thermal resistance of a layer of crust is based on data obtained from geologic exploration crust that is anyway binding for a location where civil engineering and building shall be located or where mining methods of deposits of useful substances are applied.
- The research has used data samples "in situ."
- The thermal resistance, expressed in [m^2K / W], is directly proportional to the geological thickness (measured when conducting geologic exploration) and inversely proportional to its equivalent thermal conductivity.
- A lithologic layer is a porous homogenous medium saturated with fluid, characterized by an equivalent thermal conductivity, the value of which depends on many factors:

Table 1
CHARACTERISTICS OF LAYERS - EXPLORATION DRILL F1

Depth, m	Rating
0.00 – 0.20	Topsoil
0.20 – 0.60	Transition horizon
0.60 – 2.30	Clay
2.30 – 3.30	Powder sand
3.30 – 6.00	Gravel and clayey sand

Table 2
CHARACTERISTICS OF LAYERS - EXPLORATION DRILL F2

Depth, m	Rating
0.00 – 0.20	Topsoil
0.20 – 0.60	Transition horizon
0.60 – 1.80	Clay
1.80 – 2.40	Clayey sand
2.40 – 6.00	Sand

Table 3
CHARACTERISTICS OF LAYERS - EXPLORATION DRILL F3

Depth, m	Rating
0.00 – 0.20	Topsoil
0.20 – 0.60	Transition horizon
0.60 – 1.90	Clay
1.90 – 3.40	Sand powder
3.40 – 6.00	Clay powder

Table 4
CHARACTERISTICS OF LAYERS - EXPLORATION DRILL F4

Depth, m	Rating
0.00 – 0.20	Topsoil
0.20 – 0.60	Transition horizon
0.60 – 1.80	Clay
1.80 – 2.50	Clay powder
2.50 – 6.00	Gravel and sand

Table 5
CHARACTERISTICS OF LAYERS - EXPLORATION DRILL F5

Depth, m	Rating
0.00 – 0.20	Topsoil
0.20 – 0.60	Transition horizon
0.60 – 1.70	Clay loam
1.70 – 2.40	Dust powder
2.40 – 3.50	Sand powder
3.50 – 6.00	Clay powder

Table 6

RESULTS OF LABORATORY MEASUREMENTS ON SAMPLES TAKEN FROM GEOTECHNICAL DRILLS

Name	F11	F12	F21	F22	F31	F32
Lithology	Clay	Sand powder	Clay	Clay loam	Clay	Sand powder
Horizon, m	0.60 - 2.30	2.30 – 3.30	0.6 – 1.8	1.8 – 2.4	0.6 – 1.9	1.9 - 3.4
Natural moisture, %	20.25	19.75	19.43	16.81	20.15	15.17
Porosity, ϕ, %	40.84	43.25	40.72	34.63	40.99	31.08
r_1 - volumetric fraction of solid component 1, %	59.1	20.4	50.5	18.1	52.7	0
r_2 - volumetric fraction of solid component 2, %	32.3	45.4	35.9	26.7	33.7	14.8
r_3 - volumetric fraction of solid component 3, %	8.6	32.8	13.6	54.1	11.2	56.2
r_4 -volumetric fraction of solid component 4, %	0	1.4	0	1.1	2.4	29
Humidity, S_{apa}	0.79	0.67	0.68	0.94	0.78	0.89

Name	F41	F42	F51	F52
Lihology	Clay	Clay loam	Clay loam	Sand powder
Horizon	0.6 – 1.8	1.8 – 2.5	0.6 – 1.7	1.7 – 2.4
Natural humidity, %	18.3	17.43	23.55	20.95
Porosity, ϕ	41.75	39.47	40.17	42.38
r_1 - volumetric fraction of solid component 1, %	49.5	33.4	30	20.4
r_2 - volumetric fraction of solid component 2, %	42.7	41	26.2	40.8
r_3 - volumetric fraction of solid component 3, %	6.8	25.4	40.8	37.8
r_4 -volumetric fraction of solid component 4, %	1	0,2	3	1
Humidity, S_{apa}	0.68	0.73	0.99	0.76

Table 7

THERMAL RESISTANCE ASSESSMENT FOR LAYERS OF GEOTECHNICAL DRILLS

Name	F11	F12	F21	F22	F31	F32
Thickness of layer of sample origin, δ, [m]	1.70	1	1.2	0.6	1.3	1.5
Thermal conductivity of the solid, λ_s, [W/mK]	2.0086	2.018	2.014	2.042	1.983	1.746
Thermal conductivity of the fluid, λ_f, [W/mK]	0.4595	0.3935	0.399	0.542	0.454	0.515
Thermal conductivity of the sample, λ, [W/mK]	1.1	0.995	1.042	1.29	1.084	1.195
Thermal resistance of the stratum when $A = 1\,\mathrm{m}^2$, R_t, [m^{2}K/W]	1.545	1.005	1.152	0.465	1.2	1.255

Name	F41	F42	F51	F52
Thickness of layer of sample origin, δ, [m]	1.2	0.7	1.1	0.7
Thermal conductivity of the solid, λ_s, [W/mK]	1.996	2.023	2.009	2.027
Thermal conductivity of the fluid, λ_f, [W/mK]	0.399	0.427	0.57	0.443
Thermal conductivity of the sample, λ, [W/mK]	1.019	1.095	1.211	1.064
Thermal resistance of the stratrum when $A = 1\,\mathrm{m}^2$, R_t, [m^{2}K/W]	1.178	0.639	0.9083	0.658

the nature and composition of the solids and fluids that make it up, porosity, fluid saturation.

- Each layer has its specific equivalent value for the thermal conductivity and the properties on which the assessment is carried out with samples to be determined “in situ” and with authorized laboratory analysis.

- The comparison of the thermal conductivity values obtained in this research with relatively similar data available in specific publications [1, 3, 5], led to acceptable concordance, when taking into account the many factors that influence the thermal transport.

- The study presented in this paper can be extended to deeper layers when there is an adequate geotechnical study, as well as samples taken from each layer and laboratory analysis to determine the physical properties.
- Obviously, geophysical exploration data are needed when appropriate however if that exploration is not possible then the results of the thermal resistance of the crust layers presented in the paper may constitute benchmark elements for similar studies which require such knowledge.

Nomenclature

A - The area of the heat transfer surface, [m^2]
R - The thermal resistance of the sample when $A = 1m^2$, [m^2K/W]
R' - Thermal resistance of the sample at the conduction heat transfer through a flat wall, [K/W]
S - Saturation
δ - Depth of the stratum of origin of the sample, [m]
λ -Thermal conductivity, [W/mK]
ϕ- Porosity

Subscript

Aer– Air
apa - Water
f - Fluid
i - Index
S - Solid
t -Thermal

References

1.CRISTESCU, T.,Research on interactions of media in contact in underground combustion to optimize the technological process parameters using data from experiments at Suplacu de Barcau and Videle, Petroleum-Gas University of Ploiesti, PhD Thesis, 1997
2. CRISTESCU, T., Heat Engineering, Ed. Petroleum-Gas University of Ploiesti, 2009, p.176
3. CRISTESCU, T., Thermal properties of hydrocarbon reservoirs, Universal Publishing Cartfil, Ploiesti, 1998, p. 72
4. CRISTESCU, T., Rev. Chim. (Bucharest), **57**, no. 4, 2006, p. 434
5. CRISTESCU, T.,Rev. Chim. (Bucharest), **57**, no. 1, 2006, p. 96

Manuscript received: 16.09.2013