Chapter

Estimation of Equivalent Thermal Conductivity Value Using Correlation Relationships with Other Oil Reservoir Properties

Chiș Timur, Jugastreanu Cristina and Renata Rădulescu

Abstract

In the exploitation of oil and gas reservoirs, thermal conductivity is the property of greatest importance in the application of secondary and tertiary oil fluid recovery techniques. This is why this property has been analyzed by estimating its value using several calculation models. But each model for calculating the value of this property is burdened by the fact that in the reservoir, the rocks are not like the chosen models (being made up of geological conglomerates with various inclusions). This paper presents a technique for estimating thermal conductivity (by energy transfer between overlying strata) and determining its value by a new calculation model. The paper also determined the thermal conductivity values for several rocks constituting some Romanian reservoirs, the aim of this material being to analyze the thermal behavior of rocks in condensed gas-rich areas.

Keywords: thermal conductivity, numerical modeling, heat transfer, collector rocks, oil, gas, condensate

1. Introduction

The conductivity of rocks, the constituents of oil and gas reservoirs, has not been a parameter investigated for a long time, because it was difficult to predict how fluids flowed and their temperature loss (heat transfer) in reservoir rocks [1].

After 1970, thermal conductivity was also used as a parameter in the development of hydraulic simulation models, due to the increased cost of discovery and preparation for extraction of oil and associated gas from new hydrocarbon reservoirs [2].

Models for calculating and estimating thermal conductivity were developed when tertiary oil recovery was discussed, using thermal techniques (injection of steam into the reservoir, underground combustion, flushing the collecting rocks with hot water, injection of CO_2 and flue gas, etc.) [3].

All these models developed had the ultimate goal of increasing the recovery factor of crude oil at the lowest possible price [4].

Any systematic geothermal research requires knowledge of how to transfer heat in the research environment [5, 6].

Heat transfer in oil and gas fields takes place through three main processes, namely: conduction, convection, and radiation.

Heat transfer by conduction occurs only in solid media by molecular interaction [7].

It is the main mechanism of heat transfer in the Earth's crust and the most important in geothermal probe research.

Convective heat transfer is associated with the free movement of fluids between two environments at different temperatures.

It is becoming important in geothermal areas, in particular in areas with volcanic activity and in areas with active groundwater circulation [8].

The mechanism of heat transfer by convection must be taken into account in geothermal research conducted in boreholes, because it plays a significant role in changing the natural thermal regime of the geological formations crossed.

Radiative heat transfer occurs only on the Earth's surface due to the exchange of heat between the Earth and the Sun, the rocks affected by this transfer being those from the surface or the first layers in depth (maximum 10 m).

For temperatures encountered at usual probe depths, including deep probes, the radiative transfer is negligible.

The ability of deposits of useful mineral substances to transmit and absorb thermal energy depends on the thermal conductivity of the constituent rocks.

The experimental law of thermal conduction in rocks and civil structures or Fourier's law very well defines the transfer of heat through conduction and is represented by the relation:

$$Q = -\lambda \bullet A \bullet grad\ T \tag{1}$$

But the nature of the body through which the heat transfer takes place is characterized by a parameter λ, defined in the literature as the coefficient of thermal conductivity (the amount of heat required to increase by 1 K the temperature of a surface equal to a unit of measurement, in a time unit), A is the heat transfer area (surface area), and T is the temperature difference between the heat transfer zone at the inlet and outlet:

$$\lambda = \frac{Q}{A\left|-\frac{\partial T}{\partial n}\right|} \tag{2}$$

Thermal conductivity defines the ability to accumulate and transfer a quantity of heat by the collecting rocks and the constituent fluids of the deposits of useful mineral substances.

The thermal processes that develop within the oil and gas deposits, following the application of a heat treatment or the extraction process, can be due to:

a. Conductive heat transfer due to free electrons in the outer layer of interacting rocks,

b. Radiative transfer (less existing in these deposits and due to the adsorption of energy by the black body),

c. Convective transfer due to the release of heat from moving fluids in the field.

In non-ionized gases, gases at $t \leq 1800°C$, the conductive transport of heat takes place mainly under the effect of molecular oscillations (photonic gas), which have a small amplitude, and as a result they are bodies that are poorly conductive heat.

In the case of Newtonian liquids and non-metallic solids, heat transfer through conductivity takes place both through the oscillations of molecules, because the distance between them is relatively small, and through radiation [9].

The coefficient of thermal conductivity varies with the nature of the body, with its state of aggregation, with temperature and pressure, with body moisture, with porosity, with the nature and concentration of impurities contained in the body, etc. (**Table 1**).

In the case of solutions (emulsions), the thermal conductivity is equal to the values:

- Distilled water λ = 0.611.
- Crude oil – water λ = 0.133 (Saturation with water and crude oil (35% water and 65% crude oil)).

Fluid-saturated porous medium	Porosity Φ, (%)	Density ρ, (kg/m^3)	Caloric capacity c, (kJ/kg K)	Equivalent thermal conductivity λ, (W/mK)
Saturated tiles	19,6	2080	0,766	0,877
-with air		2275	1055	2,75
-with water		-		1,36
-with crude oil		-		2,47
-with oil and gas				
Saturated clay shale (marl)	7,1	2320	0,804	1,04
- with air		2390	0,892	1,69
-with water				
Saturated limestone	18,6	2195	0,846	1,70
-with air		2390	1114	3,55
-with water				2,15
-with crude oil				2,92
-with oil and gas				
Fine saturated sand	38	1635	0,766	0,672
- with air		2020	1419	2,75
-with water				
Saturated coarse sand	34	1745	0,766	0,557
-with air		2080	1319	3,07
-with water				1,64
-with crude oil				
Saturated disaggregated tiles	40	1440	0,837	0,493
-with air		1840	1566	1,82
-with water				1,00
-with crude oil				
Saturated disintegrated silt	36	1540	0,846	0,585
-with air		1890	1476	1,79
-with water				0,96
-with crude oil				

Table 1.
Properties of porous media saturated with various fluids, at 32.2°C (90°F) [10].

The coefficient of thermal conductivity can be written as a scalar value in the case of isotropic media.

In the case of anisotropic media (inhomogeneous crystals or stratified rocks), the coefficient of thermal conductivity will be defined vectorially (in the directions of orientation):

$$\lambda_{jk} = \begin{Vmatrix} \lambda_{11} & \lambda_{12} & \lambda_{13} \\ \lambda_{21} & \lambda_{22} & \lambda_{23} \\ \lambda_{31} & \lambda_{32} & \lambda_{33} \end{Vmatrix} \tag{3}$$

Onsanger's postulate shows that the thermal conductivity matrix is symmetrical and therefore [11–13]:

Since the experiments did not confirm the existence of the rotary conduction $\lambda_{jk} = 0,\ \text{for}\, j \neq k$), the matrix (3) is reduced to the equation:

$$\lambda_{jk} = \lambda_{kj}, j \neq k \tag{4}$$

$$Q = -\lambda \bullet A \bullet grad\ T \tag{5}$$

2. Estimation of the equivalent thermal conductivity of petroleum fluid deposits

Thermal conductivity is that property defined as the heat flux (amount of heat) Q, which flows in a time τ, through a body with a given cross section and length, whose opposite faces are at temperatures t_1 and t_2:

$$\lambda = \frac{\Delta Q}{\Delta \tau} \bullet \frac{L}{A \Delta T} \tag{6}$$

The estimation of the thermal conductivity of the oil fluid deposits was made on the basis of theoretical models to describe this property and following the use of practical methods of determination in the laboratory.

The estimation of thermal conductivity can best be done based on virtual models of behavior of oil and gas fields.

The first model used to determine thermal conductivity was the series-developed geological layer model, with heat flow Q being directed perpendicular to the layers.

In this case, the thermal conductivity calculation relation can be written as:

$$\frac{1}{\lambda_z} = \frac{\Phi}{\lambda_f} + \frac{1 - \Phi}{\lambda_s} \tag{7}$$

Where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),

- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

This model considers imperfections to be nonexistent and therefore a model developed for geological layers parallel to the direction of flow of the thermal flux was chosen.

The thermal conductivity equation of the petroleum fluid reservoir can be written as follows:

$$\lambda_z = \Phi\lambda_f + (1 - \Phi)\lambda_s \tag{8}$$

Where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

This model takes into account the porosity of the rocks, but there are errors in the conductivity estimate due to the possibility of material inclusions in the reservoir's protective rocks.

A cumulative variant of the two models is expressed by the weighted geometric model, which considers that the oil fluid constituting the collecting rocks has the largest weight in the calculation of thermal conductivity:

$$\lambda_z = \lambda_f^{\Phi}\lambda_s^{1-\Phi} \tag{9}$$

where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

Paper 14 presents a model for determining thermal conductivity, based on the Maxwell equation, which assumes the reduction of petroleum fluids to interacting spheres (Euken):

$$\lambda_z = \lambda_f \frac{2\Phi\lambda_f + (3 - 2\Phi)\lambda_s}{(3 - \Phi)\lambda_f + \Phi\lambda_s} \tag{10}$$

Where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

For rocks with porosity $\Phi < 0.5$ and the thermal conductivity ratio of rocks and fluids, $\lambda s/\lambda f$, in the range 1 ÷ 300, the thermal conductivity was expressed by Beck's relation:

$$\lambda_z = \lambda_s \left[\frac{\left(2\frac{\lambda_s}{\lambda_f}+1\right) - 2\Phi\left(\frac{\lambda_s}{\lambda_f}-1\right)}{\left(2\frac{\lambda_s}{\lambda_f}+1\right) + \Phi\left(\frac{\lambda_s}{\lambda_f}-1\right)} \right] \tag{11}$$

Where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

The model developed by Vries is based on the idea that the constituent rocks of the oil reservoir consist of ellipsoidal particles dispersed in the oil fluid being analyzed.

$$\lambda_z = \frac{\Phi\lambda_f + (1-\Phi)G\lambda_s}{\Phi + (1-\Phi)\rightleftarrows G} \tag{12}$$

Where:

$$G = \frac{1}{3}\sum_{j=1}^{3}\left[1 + \left(\frac{\lambda_s}{\lambda_f} - 1\right)\xi_j\right]^{-1} \text{și} \sum_{j=1}^{3}\xi_j = 1 \tag{13}$$

and:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

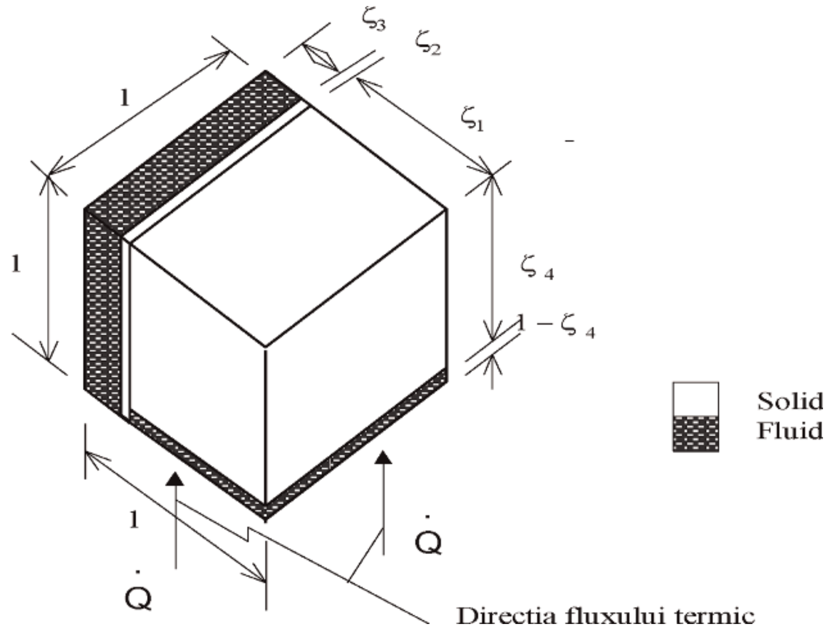

Figure 1.
Schematic of the model for calculating the thermal conductivity of petroleum fluid deposits taking into account the possibility of considering a resistor-type structure (Wyllie and Southwick) [14].

In relation 13, ξ_j is a parameter that defines the shape of the particles.

If $\xi\_1 = \xi\_2 = \xi\_3$. then Eq. 13 reduces to Eq. 10. Also de Vries considered that $\xi\_1 = \xi\_2 = 1/8$, $\xi\_3 = 3/4$, the oil deposit consists of ellipsoids of resolution with the long axis equal to six times the short axis.

The model developed by Woodside and Messmer (**Figure 1**) is a model resulting from the determination of conductivity by heating rocks and oil fluids with electromagnetic bridges and determining this property from the idea that the oil reservoir is made up of a series of particles and electolite over which geological structures are arranged in parallel.

$$\lambda_z = \frac{\zeta_1 \lambda_s \lambda_f}{\lambda_s(1-\zeta_4)+\zeta_4\lambda_f} + \zeta_2\lambda_s + \zeta_3\lambda_f \qquad (14)$$

Where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

In Eq. 14, the coefficients ζ_1, ζ_2, ζ_3, ζ_4 have values given by certain forms of rock and electrolyte arrangement.

These values of the parameters ζ_1, ζ_2, ζ_3, ζ_4 are required for the calculation of the equivalent electrical conductivity.

The use of the relation (14) for the calculation of the thermal conductivity of an unconsolidated oil fluid field leads to values very close to those obtained experimentally, when the following coefficients are used:

$$\zeta_2 = 0, \zeta_3 = \Phi - 0,03, \zeta_1 = 1 - \zeta_3, \zeta_4 = \frac{(1-\Phi)}{\zeta_1} \tag{15}$$

And this model has errors in calculating the real value of thermal conductivity, based on the idea of forming the oil field from electrolytic systems (optimal heat transfer).

Analyzing 165 thermal conductivity values, where the optimal calculation porosity was between 0.215 and 0.476, *Krupiczka* was found that in 76% of the values calculated with relation 16, the difference between the values obtained experimentally and those calculated has errors of ±30%,

The calculation formula for calculating the thermal conductivity proposed by this model is:

$$\lambda_z = \lambda_f \left(\frac{\lambda_s}{\lambda_f}\right)^{A' + B' \log\frac{\lambda_s}{\lambda_f}} \tag{16}$$

Where:

$$A' = 0,280 - 0,757 log\Phi \; şi B' = -0,057 \tag{17}$$

and:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks.

3. Evaluation of thermal conductivity simulation models

Following the experiments on the cores extracted from potential areas supplying oil fluids, we managed to determine the conductivity of the rocks, their porosity and density.

The data obtained were used to simulate the thermal conductivity of deposits saturated with gas, water (density is 1000 kg/m^3), pure crude oil (density is 790 kg/m^3), and crude oil mixed with 35% water ((density is 863 kg/m^3).

At the same time, we created our own model for simulating thermal conductivity, based on the statistical interpretation of the data obtained from the calculations performed with five analyzed models (**Tables 2–5**).

Figure 2.
Thermal conductivity tester.

The model developed in this paper starts from the idea that the analyzed rock is not pure (i.e., the density of the analyzed rock was introduced in the calculation).

The model was tested on the cores analyzed in the apparatus of **Figure 2** and shown in the tables below for all existing fluids in the field.

We also introduced porosity in the calculation as a basic factor in the calculation of total conductivity.

$$\lambda_z = \frac{1}{(\rho_{r})} \bullet \left(\lambda_f^{(1-\theta)} \bullet \lambda_f^{\theta}\right) \quad (18)$$

Where:

- λ_f is the coefficient defining the thermal conductivity of the reservoir fluid, W/(m K),
- λ_s is the coefficient of thermal conductivity of the constituent rocks of the deposit, in which the oil fluids are located, W/(m K),
- Φ is the porosity of the rocks,
- ρ_r is density of the rocks, kg/m^3,
- λ_z is conductivity of fluids of the reservoir, W/m K,

Figures 3–6 give the differences between the calculated values of thermal conductivity with the six models, with porosity and thermal conductivity (kr) determined using the apparatus in **Figure 2**.

Figures 7 and **8** show the calculated thermal conductivity values with the six models according to literature data.

Rock type	k_r W/mK	porosity, (10%)	Series model k_z	Parallel model k_z	Weighted geometric model, k_z	Beck model k_z	Model Krupiczka k_z	Chiș, Jugăstreanu k_z
Cracked limestone chalk	0,831,936	0,5	4,45	0,48	0,294	0,42	1,35	1,07
Chalk	1,145,466	2,2	15,88	1,09	0,405	−0,50	1,21	1,37
Compact clay	0,267,246	1,9	11,25	0,01	0,094	0,04	0,34	0,35
Marl	0,285,348	1,2	8,53	0,10	0,101	0,11	0,38	0,37
Chalk	0,476,826	1,3	9,37	0,03	0,168	0,06	0,61	0,61
Conglomerate	0,454,902	1,2	8,79	0,07	0,161	0,08	0,60	0,63
Compact clay	0,723,492	1,5	10,85	0,17	0,256	0,06	0,89	0,95
Compact clay	0,814,926	1,9	13,51	0,49	0,288	0,22	0,93	1,05
Floor tiles	0,878,766	1,99	14,18	0,61	0,311	0,28	0,99	1,12
Cracked limestone/ dolomite	0,701,568	1,02	7,82	0,12	0,248	0,12	0,95	1,08
Compact limestone	0,826,812	3	20,66	1,26	0,292	0,51	0,84	1,04
Compact limestone/ dolomite	0,869,232	1,5	10,96	0,24	0,307	0,10	1,05	1,09
Marne with inclusions	0,38,199	1,4	9,72	0,03	0,135	0,06	0,49	0,54
Limestone tiles	0,635,334	1,1	8,30	0,08	0,225	0,09	0,84	0,83
Chalk	0,664,734	1,5	10,79	0,14	0,235	0,04	0,82	0,85

Table 2.
The values of thermal conductivity calculated with simulation models, the fluid in the rock is crude oil.

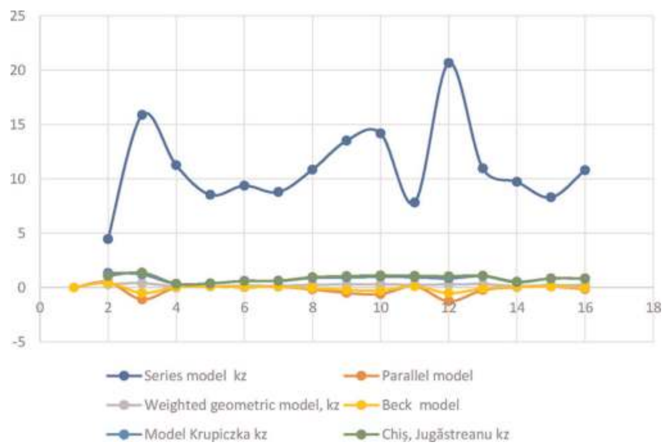

Figure 3.
The variation of the conductivity parameters of the analyzed deposits of the fluid contained in the rocks is crude oil.

Rock type	k_r W/mK	porosity, (10%)	Series model k_z	Parallel model k_z	Weighted geometric model, k_z	Beck model k_z	Model Krupiczka k_z	Chiş, Jugăstreanu k_z
Rock type	0,83	0,5	0,23	0,23	0,301	0,43	1,32	1,09
Cracked limestone chalk	1,15	2,2	0,06	0,06	0,414	0,50	1,19	1,40
Chalk	0,27	1,9	0,09	0,09	0,097	0,05	0,33	0,36
Compact clay	0,29	1,2	0,12	0,12	0,103	0,11	0,37	0,38
Marl	0,48	1,3	0,11	0,11	0,172	0,06	0,60	0,62
Chalk	0,45	1,2	0,12	0,12	0,164	0,09	0,58	0,64
Conglomerate	0,72	1,5	0,09	0,09	0,262	0,06	0,87	0,98
Compact clay	0,81	1,9	0,08	0,08	0,295	0,22	0,91	1,08
Compact clay	0,88	1,99	0,07	0,07	0,318	0,28	0,97	1,15
Floor tiles	0,70	1,02	0,13	0,13	0,254	0,12	0,92	1,10
Cracked limestone/ dolomite	0,83	3	0,05	0,05	0,299	0,51	0,82	1,07
Compact limestone	0,87	1,5	0,09	0,09	0,314	0,10	1,03	1,11
Compact limestone/ dolomite	0,38	1,4	0,11	0,11	0,138	0,06	0,48	0,55
Marne with inclusions	0,64	1,1	0,12	0,12	0,230	0,10	0,82	0,84
Limestone tiles	0,66	1,5	0,10	0,10	0,240	0,04	0,80	0,87

Table 3.
The values of thermal conductivity calculated with simulation models, the fluid in the rock is water and crude oil.

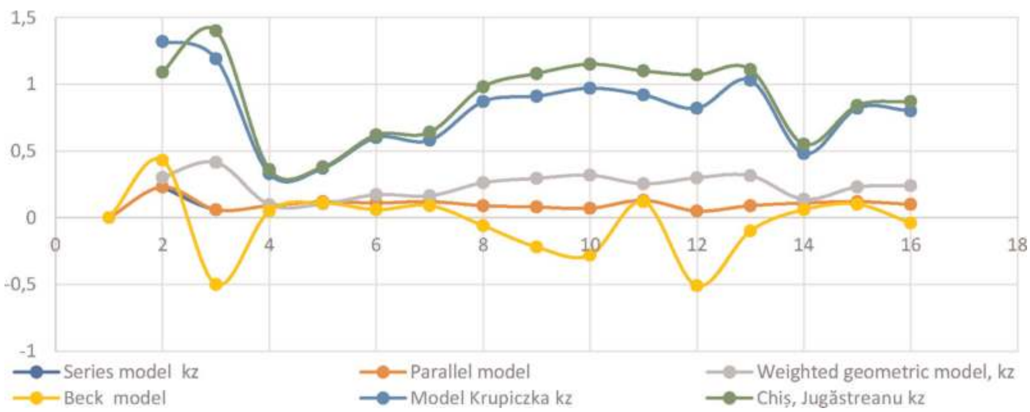

Figure 4.
The variation of the conductivity parameters of the analyzed deposits of the fluid contained in the rocks is water and crude oil.

Rock type	k_r W/mK	porosity, (10%)	Series model k_z	Parallel model k_z	Weighted geometric model, k_z	Beck model k_z	Model Krupiczka k_z	Chiş, Jugăstreanu k_z
Rock type	0,83	0,5	0,70	0,72	1382	0,72	0,25	5,01
Rock type	1,15	2,2	0,39	0,03	1902	0,15	0,31	6,45
Cracked limestone chalk	0,27	1,9	3,88	0,92	0,444	1,33	0,08	1,65
Chalk	0,29	1,2	0,79	0,68	0,474	0,71	0,08	1,76
Compact clay	0,48	1,3	0,67	0,65	0,792	0,66	0,14	2,87
Marl	0,45	1,2	0,66	0,64	0,756	0,65	0,13	2,95
Chalk	0,72	1,5	0,57	0,55	1202	0,56	0,21	4,48
Conglomerate	0,81	1,9	0,50	0,43	1353	0,45	0,23	4,96
Compact clay	0,88	1,99	0,47	0,35	1460	0,39	0,24	5,27
Compact clay	0,70	1,02	0,61	0,61	1165	0,61	0,20	5,07
Floor tiles	0,83	3	0,40	0,18	1373	0,28	0,23	4,90
Cracked limestone/ dolomite	0,87	1,5	0,53	0,48	1444	0,50	0,25	5,10
Compact limestone	0,38	1,4	0,80	0,70	0,634	0,73	0,11	2,54
Compact limestone/ dolomite	0,64	1,1	0,61	0,61	1055	0,61	0,18	3,88
Marne with inclusions	0,66	1,5	0,59	0,58	1104	0,59	0,19	4,00

Table 4.
The values of thermal conductivity calculated with simulation models, the fluid in the rock is water.

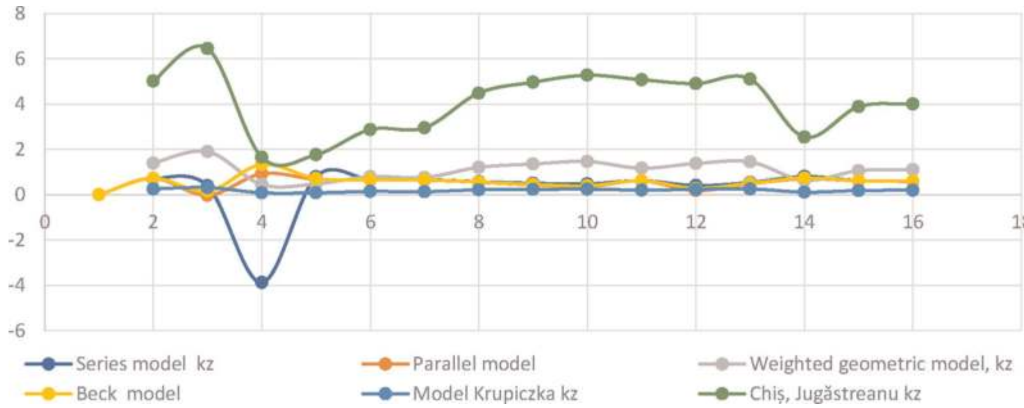

Figure 5.
The variation of the conductivity parameters of the analyzed deposits of the fluid contained in the rocks is water.

Rock type	k_r W/mK	porosity, (10%)	Series model k_z	Parallel model k_z	Weighted geometric model, k_z	Beck model k_z	Model Krupiczka k_z	Chiş, Jugăstreanu k_z
Rock type	0,83	0,5	0,07	0,43	0,077	0,36	5,91	0,28
Rock type	1,15	2,2	0,02	1,30	0,106	0,62	3,99	0,36
Cracked limestone chalk	0,27	1,9	0,02	0,18	0,025	0,08	1,15	0,09
Chalk	0,29	1,2	0,03	0,02	0,026	0,00	1,40	0,10
Compact clay	0,48	1,3	0,03	0,10	0,044	0,05	2,24	0,16
Marl	0,45	1,2	0,03	0,05	0,042	0,02	2,20	0,16
Chalk	0,72	1,5	0,02	0,31	0,067	0,17	3,14	0,25
Conglomerate	0,81	1,9	0,02	0,67	0,075	0,34	3,15	0,28
Compact clay	0,88	1,99	0,02	0,80	0,081	0,40	3,30	0,29
Compact clay	0,70	1,02	0,03	0,02	0,065	0,02	3,60	0,28
Floor tiles	0,83	3	0,01	1,55	0,076	0,62	2,59	0,27
Cracked limestone/ dolomite	0,87	1,5	0,02	0,38	0,080	0,21	3,73	0,28
Compact limestone	0,38	1,4	0,02	0,11	0,035	0,05	1,76	0,14
Compact limestone/ dolomite	0,64	1,1	0,03	0,03	0,059	0,01	3,16	0,22
Marne with inclusions	0,66	1,5	0,02	0,28	0,061	0,15	2,90	0,22

Table 5.
The values of thermal conductivity calculated with simulation models, the fluid in the rocks is natural gases.

The relative error (**Tables 7–9**) of the computationally determined data with the six models compared with the literature data shows that the Chiș model is closest to the values determined in other laboratories.

The error is due to the fact that the analyzed samples are impure.

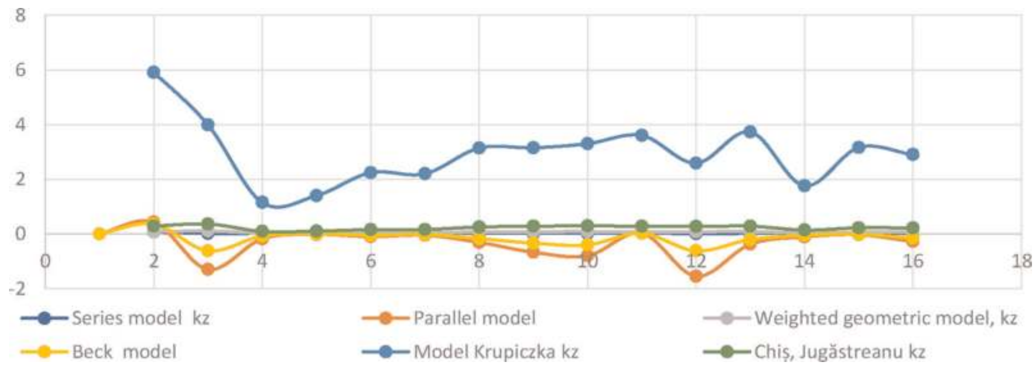

Figure 6.
*Variation of the conductivity parameters of the analyzed deposits of the fluid contained in the rocks is natural gases (**Table 6**).*

Fluid-saturated porous medium	Thermal conductivity W/mK, k_l	Series model k_z	Parallel model k_z	Weighted geometric model, k_z	Beck model k_z	Model Krupiczka k_z	Chiș, Jugăstreanu k_z
with air	0,877	0,02	0,80	0,081	0,40	3,30	0,29
with water	2,75	0,47	0,35	1460	0,39	0,24	5,27
with oil	1,36	14,18	0,61	0,311	0,28	0,99	1,12
with oi land gas	2,47	0,07	0,07	0,318	0,28	0,97	1,15

Table 6.
*Thermal conductivity values calculated with simulation models and taken from the literature (**Table 1** and references [10]) for saturated tiles.*

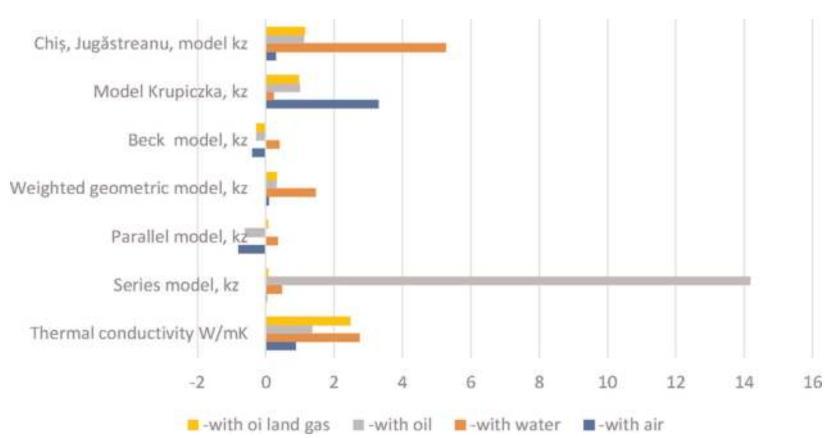

Figure 7.
Thermal conductivity values calculated with simulation models and taken from the literature for saturated tiles.

Fluid-saturated porous medium	Thermal conductivity W/mK, kl	Series model kz	Parallel model kz	Weighted geometric model, kz	Beck model kz	Model Krupiczka kz	Chiş, Jugăstreanu kz
-with air	0,88	0,98	1,91	0,91	1,46	2,76	0,67
-with water	2,75	0,83	0,87	0,47	0,86	0,91	0,92
-with oil	1,36	9,43	1,45	0,77	1,21	0,27	0,18
-with oil land gas	2,47	0,97	0,97	0,87	1,11	0,61	0,53

Table 7.
Relative error of the chosen model calculation based on literature values for saturated tiles.

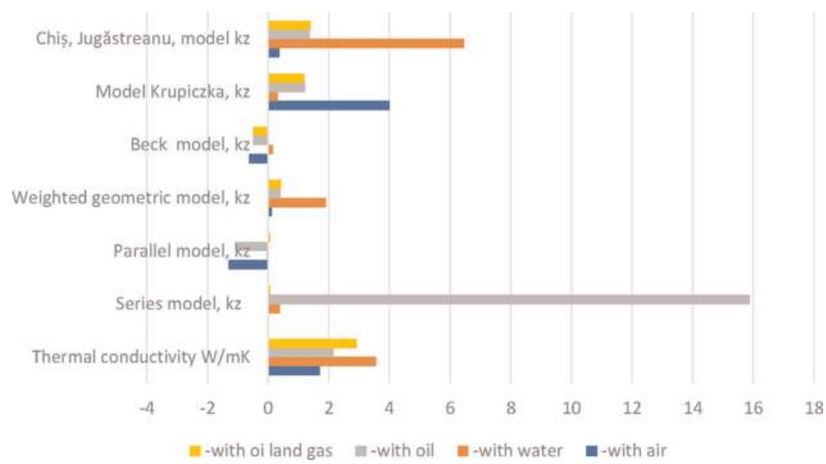

Figure 8.
Thermal conductivity values calculated with simulation models and taken from the literature for chalk.

Fluid-saturated porous medium	Thermal conductivity W/mK, k_l	Series model k_z	Parallel model k_z	Weighted geometric model, k_z	Beck model k_z	Model Krupiczka k_z	Chiş, Jugăstreanu, model k_z
-with air	1,7	0,02	1,30	0,106	0,62	3,99	0,36
-with water	3,55	0,39	0,03	1902	0,15	0,31	6,45
-with oil	2,15	15,88	1,09	0,405	0,50	1,21	1,37
-with oi land gas	2,92	0,06	0,06	0,414	0,50	1,19	1,40

Table 8.
*Thermal conductivity values calculated with simulation models and taken from the literature (**Table 1** and references [15]) for chalk.*

Fluid-saturated porous medium	Thermal conductivity W/mK, kl	Series model kz	Parallel model kz	Weighted geometric model, kz	Beck model kz	Model Krupiczka kz	Chiş, Jugăstreanu kz
-with air	0,88	0,99	1,76	0,94	1,36	1,35	0,79
-with water	2,75	0,89	1,01	0,46	0,96	0,91	0,82
-with oil	1,36	6,39	1,51	0,81	1,23	0,44	0,36
-with oil land gas	2,47	0,98	0,98	0,86	1,17	0,59	0,52

Table 9.
Relative error of the chosen model calculation based on literature values for chalk.

4. Conclusion

Analyzing the values obtained through models with data from the literature, we can say the following:

- The values closest to the data from the specialized literature are offered by the Chis model, Jugastreanu,
- The parallel model and the Beck model provide negative conductivity results,
- The Chiş model, Jugastreanu has errors in the calculation of the thermal conductivity of the deposits affected by water, because the reservoir water was not introduced in the calculation but water without salinity,
- Air testing, compared with the calculation of the conductivity of rocks with natural gas, brings higher values of the conductivity of the deposits.

In conclusion, we can say that the theoretical models for calculating the thermal conductivity coefficient are useful in defining how to establish the optimal tertiary oil recovery technique, but for the correct estimation of the amount of petroleum products in the field, it is necessary to determine this property (thermodynamic coefficient) by laboratory analysis.

Author details

Chiș Timur[1]*, Jugastreanu Cristina[2] and Renata Rădulescu[2]

1 Ovidius University Constanta, Constanta, Romania

2 Oil-Gas University, Ploiesti, Romania

*Address all correspondence to: timur.chis@gmail.com

References

[1] Abdulagatova ZZ, Abdulagatov IM, Emirov SN. Effect of pressure, temperature, and oilsaturation on the thermal conductivity of sandstone up to 250 MPa and 520 K. Journal of Petroleum Science and Engineering. 2010;**73**:141-155

[2] Alishaev MG, Abdulagatov IM, Abdulagatova ZZ. Effective thermal conductivity of fluid saturated rocks: Experiment and modeling. Engineering Geology. 2012;**135–136**:24-39

[3] Burger J, Sourieau P, Combarnous M. Title Thermal Methods of Oil Recovery. Houston, TX: Gulf Pub; 1986

[4] Cai KP, Fan SH, Zhang BJ, et al. Reservoir on sedimentation diagenetic feature and reservoir relationship of Shaximiao formation in South District of West Sichuan. Natural Gas Exploration & Development. 2004;**27**(3):11-17 (in Chinese with English Abstract)

[5] Woodside W, Messmer J. Thermal conductivity of porous media: I. unconsolidated sands. Journal of Applied Physics. 1961;**32**:1688-1699

[6] Woodside W, Messmer J. Thermal conductivity of porous media: II. Consolidated sands. Journal of Applied Physics. 1961;**32**:1699-1706

[7] Ray L, Bhattacharya A, Roy S. Thermal conductivity of higher Himalayan Crystallines from Garhwal Himalaya. India Tectonophysics. 2007; **434**:71-79

[8] Ren JS. On the post-Variscan global tectonic stages. Acta Geologica Sinica. 1987;**61**(1):21-31 (in Chinese with English Abstract)

[9] Tabatabai SM, Jugastreanu C, Chis T. Mathematical modeling of the geothermal gradient of oil and gas deposits. International Journal of Engineering Research and Applications. 2022;**12**(2):21-27 (Series-I) indexată în Google Scholar

[10] Jugastreanu C, Tabatabai SM, Chis T. Thermal properties of oil and gas reservoires rocks modeling. International Journal of Research – GRANTHAALAYAH. 2022;**10**(2): 125-144

[11] Tabatabai SM, Jugastreanu C, Chis T. New equation of geophysical prospecting of oil and gas field. IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG). 2022;**10**(1): 25-32

[12] Jugastreanu C, Tabatabai SM, Chis T. History of research on the thermal regime of oil and gas fields. International Journal of Innovations in Engineering and Technology. February 2022;**21**(3): 37-43. ISSN: 2319-1058. DOI: 10.21172/ijiet.213.05

[13] Jugastreanu CR, Petrache ST, Chis T. The impact of offshore seismic studies on the marine environment. American Journal of Engineering Research (AJER). 2021;**10**(8):109-113

[14] Jugastreanu CR, Petrache ST, Chis T. Numerical modeling of oil pollution. International Journal of Engineering Science Invention (IJESI). 2021;**10**(7): 56-60

[15] Petrache S, Jugastreanu CR, Chis T. Numerical modeling of sulfur removal from waste gas from oil refining process. International Journal of Engineering Research and Applications. 2021;**11**(7): 12-16