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EXPERIMENTAL DETERMINATION OF THE DEGREE OF INFLUENCE OF GRAVITATIONAL CONVECTION AND CASING PIPES ON THE NATURAL TEMPERATURE DISTRIBUTION IN BOREHOLES*

(Presented by Academician L. I. Sedov, January 5, 1963)

As is known, the influence of convective currents in a borehole and of conductive heat transfer through casing pipes is expressed theoretically in the fact that, in a borehole, as a result of the nonuniform distribution of temperature, motions arise that tend to bring the air or liquid filling the borehole into thermal equilibrium. The degree of such influence should increase with increasing borehole diameter, its depth, the thickness and number of casing strings, the geothermal gradient, and also with decreasing viscosity of the filler (clay mud–water –air). In general, disturbing currents resulting from counterflow motion under a positive geothermal gradient should cause a rise in temperature in the near-mouth part and cooling at the bottom, which should lead to "leveling" of the temperature along the borehole shaft and to a decrease in the gradient ([1,2]).

Since the indicated phenomenon has essentially not been studied experimentally, some investigators overestimate its influence to such an extent that they sometimes attribute to it any deviations from the normal temperature regime. Most investigators, however, consider the influence of convection negligible ([3]), which is confirmed by the following facts observed by the author ([4,5]):

1. Temperatures measured in deep, cased boreholes that have remained at rest for a long time coincide with temperatures measured in shallow boreholes of small diameter drilled in the same area under analogous geological-hydrogeological and geomorphological conditions without casing.
2. In the layer of annual amplitudes, completely identical breaks in thermograms are observed both in shallow and in deep boreholes; this should not have been observed in the latter if convection had a substantial influence, since in that case the temperature along the entire borehole shaft would have become equalized.

In the course of field experimental work devoted to studying the influence of convection and casing pipes, the influence of surface factors was first studied, chiefly the "inflow" of cold air in the winter period. Studies at 14 sites showed that, with mine-well diameters of 1.0–1.5 m, in the layer of constant annual temperatures (below 20 m), with an open mouth, the mean annual temperature proved to be 0.3–1.8° lower than in boreholes at the same depth. In those cases where insulating devices were constructed over the mine wells, a higher temperature was observed (by 0.6° in the village of Krasnosel' skoe, Crimea). Apparently, this is connected with the fact that open wells are cooled by "inflowing" cold heavy air in winter as a result of convection, but cannot warm up in summer, since heat from above is transferred only by conduction. Evidently, for this very reason, even in hot months, ice remains on the walls of wells in some regions (Minusinsk Basin).

* N. V. Sedov took part in the field and laboratory work.

In boreholes (see Table 1), with a diameter of 200 mm (borehole No. 2a) and a temperature difference of up to 12° (−6 ÷ +6°), the influence of "inflow" is felt down to 25 m, while when the diameter is reduced to 115 mm (borehole No. 1) it practically disappears already at a depth of 17.5 m.

Table 1

Determination of the influence of air "inflow" into a borehole in winter on the natural temperature distribution (Zagorsk)

Depth, m	Borehole No. 2a (6–7 II 1961): temperature, °C, with closed mouth	Borehole No. 2a (6–7 II 1961): temperature, °C, with open mouth	Borehole No. 2a (6–7 II 1961): Δt, °C	Borehole No. 1 (22–23 II 1962): temperature, °C, with closed mouth	Borehole No. 1 (22–23 II 1962): temperature, °C, with open mouth	Borehole No. 1 (22–23 II 1962): Δt, °C
15.0	6.21	6.15	−0.06	6.65	6.60	−0.05
17.5	6.20	6.15	−0.05	6.63	6.61	−0.02
20.0	6.20	6.17	−0.03	6.58	6.58	0.00
22.5	6.27	6.25	−0.02	6.64	6.64	0.00
25.0	6.25	6.21	−0.04	6.55	6.55	0.00
27.5	6.26	6.25	−0.01	–	–	–
30.0	6.40	6.38	−0.02	–	–	–
32.5	6.37	6.35	−0.02	–	–	–

Note. The air temperature at the ground surface averaged −6°.

The study of the distorting influence of "ascending" convection in a borehole and of conductive heat transfer from the bottomhole along casing pipes to the

Figure 1

Figure 1: Figure 1

mouth of the borehole was carried out in summer in order to eliminate the influence of "inflow." Since the influence of convection and the influence of pipes act in the same direction, and the degree of this influence should be manifested to the greatest extent in the near-mouth part of the borehole, the experiments were carried out according to the following method, developed by the author. Near a deep borehole cased with pipes, shallow boreholes of small diameter (25 mm) without casing were drilled at various distances. During temperature measurement they were reliably tamped along the entire shaft with heat-insulating material (felt, cotton wool, clay) to avoid convection. Temperature measurements from points–

Fig. 1. Determination of the degree of influence of convection and casing pipes on the natural temperature distribution in boreholes in the city of Poltava (20–21 VII 1962). *1* –insulating disk; *2* –convection currents.

with an accuracy of $±$0.02° were made in all wells simultaneously at the same depth below the layer of diurnal amplitudes. For control in the deep well, in addition, temperature measurements were made above an insulating disk, which was made of several layers of plywood, technical felt, and cotton wool and fit tightly against the walls of the well, blocking access to convection currents from below. In the event that convection and the pipes introduced some distortions into the natural temperature field, deviations of the isotherms should have been observed near the deep well, as is usually depicted [2].

In order to take into account the diversity of geothermal, geological-hydrogeological, and physical-geographical conditions, experimental field work was carried out within three large regions (the Fore-Caucasus, the Dnieper-Donets depression, and the Ukrainian crystalline shield). Everywhere completely analogous results were obtained, brief information on which is given below.

Table 2

Determination of the influence of convection on the natural temperature distribution in well No. 23, Poltava, by means of an insulating disk, 21 VII 1962.

Depth, m	Temperature, °C: free convection	Temperature, °C: disk installed
7.5	9.02	9.00
9.0	9.24	9.25
10.0	Insulating disk	Insulating disk
12.5	9.37	9.35

Fig. 2. Determination of the degree of influence of convection and casing pipes on the natural temperature distribution in well No. 16, settlement of Zimnyaya Stavka, Stavropol Territory (31 V–5 VI 1962).

Figure 2: Fig. 2. Determination of the degree of influence of convection and casing pipes on the natural temperature distribution in well No. 16, settlement of Zimnyaya Stavka, Stavropol Territory (31 V–5 VI 1962).

In the city of Poltava the investigations were carried out in two wells (wells Nos. 23 and 24) with the following basic parameters: well depth 442 m; casing was made with two strings of diameter 6 and 8 inches; geothermal gradient 0.26×10^{-3} °C/cm; static water level 71 m. Graphical processing of the results of thermometric investigations in deep and shallow (control) wells of this site convincingly shows that the isotherms, somewhat distorted under the influence of surface causes in the layer of monthly temperature oscillations*, already at a depth of 10 m are completely straight, and neither the pipes nor convection introduce practical distortions into the temperature field (Fig. 1). When an insulating disk was installed in well No. 23, the same result was obtained (Table 2).

In the "dry" well No. 74 of the city of Makhachkala, more than 512 m deep, cased with pipes 8 inches in diameter, with a geothermal gradient of 0.44×10^{-3} °C/cm, the temperature proved to be the same as in the rocks at the same depth within a radius of up to 13.5 m (Table 3).

Fig. 2. Determination of the degree of influence of convection and casing pipes on the natural temperature distribution in well No. 16, settlement of Zimnyaya Stavka, Stavropol Territory (31 V–5 VI 1962).

Finally, measurements in well No. 16 of the settlement of Zimnyaya Stavka, Stavropol Territory, which is distinguished by an extremely favorable combination of circumstances for intensifying the distorting role of convection and casing pipes, also gave a negative result (Fig. 2). The well is cased with three strings of casing pipes with diameters from 6 to 20 inches. At the bottom of the well (3174 m) a very high temperature (130°) was recorded, and the geothermal

* These distortions are not connected with the influx of heat from below, not only because they rapidly attenuate with depth, but also because of the opposite sign.

the gradient reaches 0.4×10^{-3} °C/cm throughout the entire borehole. In addition, the borehole is filled with air from the mouth down to 117 m.

Summing up, it may be asserted that the distorting influence of convective currents in the borehole, as well as of conductive heat transfer along the casing pipes, is so negligible that it lies beyond the accuracy limits of the instruments used (±0.02°).

Table 3

Determination of the distorting influence of convection and casing pipes on the natural temperature distribution in borehole No. 74, Makhachkala, using shallow boreholes (11-12 VI 1962)

	1.25	2.50	3.75	5.00	6.25	7.50	8.60	8.75	10.0	11.00	11.25
Depth, m	1.25	2.50	3.75	5.00	6.25	7.50	8.60	8.75	10.0	11.00	11.25
T-ra, °C: borehole No. 74	19.1	15.1	13.1	12.8	13.1	13.6	–	13.9	14.1	–	14.1
borehole No. 1-N (13.5 m from borehole No. 74)	18.8	14.4	13.1	12.8	13.2	13.6	13.8	–	14.1	14.1	–
Δt, °C	0.3	0.7	0.0	0.0	0.1	0.0	–	–	0.0	–	–

Substantial distortions in the temperature field are introduced by the "inflow" of cold air during the winter period into shaft wells. With an open mouth, the mean annual temperature in this case proves to be lower than the natural one by 0.3-1.8° down to depths of more than 50 m. In boreholes, the influence of "inflow" is temporary in character and has practically no effect on the absolute value of the mean annual temperature.

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