Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Geothermal Resources of Ukraine

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Keywords: geothermal resources, calculation of geothermal reserves, Ukraine

ABSTRACT

In this study, the density of promising geothermal resources of a category C3 (*W*) for different depths of drilling (3, 4, 5 and 6 km; *W3*, *W4.5* and *W6*, respectively) is estimated. In the Ukraine it was determined in 12.000 boreholes. The *W* calculations method is conventional. It was established by the Ministry of Geology of the USSR in 1990, Dyad'kin et al. (1991). The total reserves (*TR* = sum of C3) of the central part of the Ukraine (Ukrainian Shield) with the density higher than 2,5 t.s.f./m^2 are 0,04x10^{12} t.s.f.. The western area has *TR* value about 0,2x10^{12} t.s.f.. The southern area has *TR* about 0,3x10^{12} t.s.f.. The eastern area has *TR* about 0,19x10^{12} t.s.f.. The general reserves of all mineral fuels of the Ukraine are 0,04x10^{12} t.s.f..

1. INTRODUCTION

Geothermal energy exploration is progressing rapidly. It has great potential to become an important energy supply technology due to its environmental amenities and ubiquitous distribution. For example, in modern geothermal systems all water is re-injected to the source layer. The Ukraine geothermal resources are based on the thermal data analysis (e.g., heat flow, geothermal gradient, fluid flow rates, etc.). In every region it is different due to geological structures and needs its own calculation parameters.

2. HEAT FLOW OF UKRAINE

The *W* values were calculated from the heat flow values. Geothermal studies on the territories of Ukraine have been under way for about 35 years. Many important features of the thermal field still remain unstudied. This applies in particular to the Ukrainian Shield and to the southern parts of the Carpathian region. For that reason, new heat flow (HF) calculations (in the 10 last years) were conducted (Figure 6) in the Ukrainian Shield (Ush) - 1500, Dnieper-Donets basin (DDB) - 1600, Donbas (DB) - 5500, Carpathian region (CR)- 500, Crimea and South-Ukrainian monocline – 300, running to between 30 and 6000 meters in depth, Gordienko et al. (2002). The HF values were determined in oil and water wells and in ore holes. The heat flow values were largely calculated on the basis of the average geothermal gradient between the bottom of the bore hole and the surface (the temperature at the surface ranging from 6 to 12 ºC) and average heat conductivity within the aforementioned depth range. The geothermal gradient varies from 1.7 to 6 ºC/100m. The thermal conductivity of rocks in the trough increased with depth and varies inside the region from 1.7 to 2.7 W/m ºC. In several sites the heat flow was determined based on the results of high-precision temperature measurements in shallow bore holes.

The accuracy of heat flow determinations was established by comparing the results with those obtained earlier by other methods in the same bore holes. The error does not exceed 8%.

All the heat flow values (including those measured earlier) were adjusted to allow for the effect of the paleoclimate and the structural effect. The effect of the movement of subsurface waters was taken into account in the measurements within shallow bore holes.

A map of the Ukraine deep heat flow was scaled at 1:2.500.000, although the required density of measurements in the central part of the region had not been attained. The heat flow pattern is complex. The background value averages to 45 mW/m^2, ranging from 35 to 50 mW/m^2 in different parts of the region.

The western and southern regions of Ukraine are part of the Transeuropean zone of recent activization and phanerozoic geosynclines. Thermal anomalies there occur sporadically. In areas of reliably identified positive thermal anomalies (around 60 mW/m^2 isolines) the values reach 65-130 mW/m^2, i.e. by 20-80 mW/m^2 higher than the background ones. Volyn' anomaly with low HF (an average of 34 mW/m^2) was identified in the northernmost part of the Carpathian region and Ukrainian Shield.

3. A CALCULATION OF GEOTHERMAL RESOURCES

The region in question is promising for commercial use of geothermal energy. Its resources have been assessed by the method developed at Leningrad Mining Institute, Dyad'kin et al. (1991).

To ensure hot water supply, the average temperature (*T*) of the water being extracted was assumed to be 60 ºC and the temperature of the water being disposed was taken to be 20 ºC. For heating, the temperatures of 100 and 40 ºC, respectively, are sufficient. To produce electricity, the water should be heated to 210 ºC and to dispose, the water should be 70 ºC.

The formula to calculate the reserves is:

$$W = N\,K\,C\,T\,(H_b - H_t) \qquad (1)$$

where *N* is the norm of fuel consumption to produce consumer heating (0,34x10^{-10} tonnes of standard fuel) and *K* is the thermal extraction coefficient (0.125). The K calculation method is given by Gordienko et al. (2002). The *K* value slightly changes with geothermal gradient. Its mean value does not differ from that established by the Ministry of Geology of USSR in 1990. *C* is the volumetric heat capacity of rocks: 2.5.10^6 J/m^3 ºC. The *C* value was determined from 8500 rock samples. It is practically the same in different regions of Ukraine. Its mean value, 2,3x10^6 J/m^3 ºC, coincides with that used in Dyad'kin et al. (1991) and is similar to that used in Tester et al. (1990). *T* is the temperature difference between the heat-transfer agent and its dumping; 40, 60, and 140 ºC; H_b is the depth of the bore hole where the lower temperature has been determined.

In fact, *W6* = 0.00042 (H_b-H_t); *W4.5*=0.00064 (H_b-H_t) and *W3*=0.00157 (H_b-H_t) are given in tonnes of standard fuel/m^2 and *H* in meters.

The H_t is a depth at which the temperature ensures average *T* values of 60, 100, or 210 °C within the respective H_b-H_t ranges. It is determined as

$$H_t = (T_b - T_t) / 0.5\, g \qquad (2)$$

where T_t is the temperature of the heat-transfer agent (60, 100, or 210), *g* is the average geothermal gradient within that range. In the event that *T* is high at the lower point, the upper point would be perceived as occurring above surface. In order to rule out this situation, a restriction is imposed on the *T* at the upper point: It should be 10 ºC higher than the temperature of the water being dumped, more specifically, 30, 50, and 80 ºC. This allows us to consider the difference between the estimated average *T* of the extracted water and the standard values of 60, 100, and 210 ºC. It creates an additional factor in the formula for calculating *W*. T_{av} is equal to 20, 40, or 70 for 40, 60, or 140 ºC, respectively.

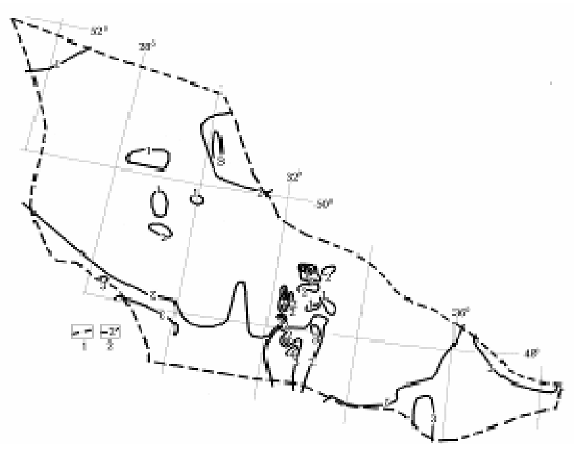


Figure 1. The results of W6 calculations on the Ukrainian shield1 - borders of the region, 2 - isolines of W

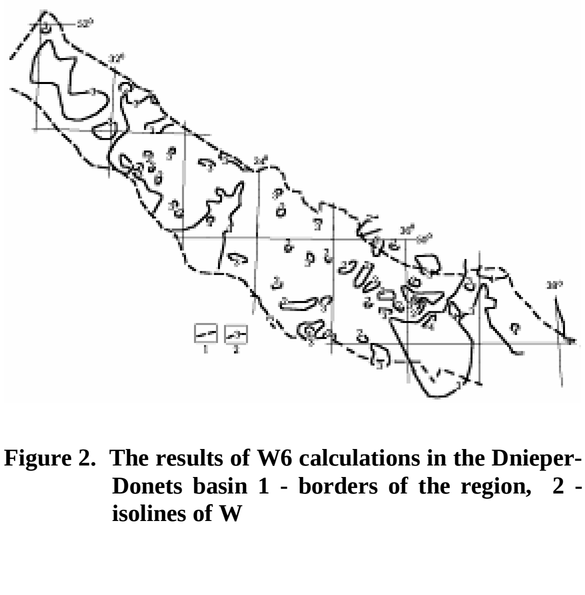


Figure 2. The results of W6 calculations in the Dnieper-Donets basin 1 - borders of the region, 2 - isolines of W

The actual task reduces to the calculation of *T* for the given region (for the given pattern of thermal conductivity distribution with depth – see Table 1) at various heat flow values followed by the calculation of *W* for different drilling depths. The calculations were performed for all the depths at which *T* was measured, and the results were compared with those observed. The deviations do not exceed 1-5 ºC. It is an insignificant value and does not produce any appreciable error in *W* estimates.

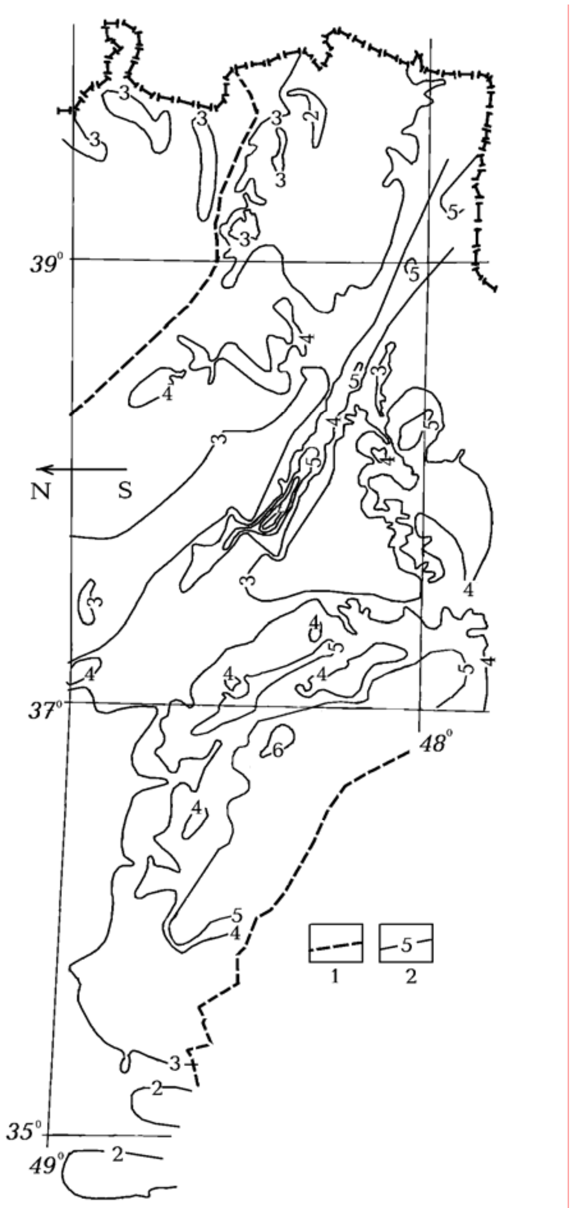


Figure 3. The results of W6 calculations in the Donbas 1 - border of region, 2 - isolines of W

Table 1. Thermal conductivity (W/m.0C) rocks in regions of Ukraine

ΔH, km	1	2	2-3
0-1,5	1,85	2,65	2,45
1,5-3	2,65	2,65	2,45
3-4,5	2,65	2,65	2,45
4,5-6	2,65	2,65	2,45
0-6	2,39	2,65	2,45
ΔH, km	**3**	**4**	**5 and 7**
0-1,5	1.8	2.1	2,65
1,5-3	2.25	2.65	2,65
3-4,5	2,65	2.65	2,65
4,5-6	2,65	2,65	2,65
0-6	2,28	2,49	2,65
ΔH, km	**5,7-slopes**	**6-borders**	**6**
0-1,5	1,7	1,8	1,8
1,5-3	2,65	2,05	2,05
3-4,5	2,65	2,65	2,2
4,5-6	2,65	2,65	2,3
0-6	2,32	2,22	2,07
ΔH, km	**8**	**9**	**10**
0-1,5	2	1.8	1.6
1,5-3	2.1	2.2	2.05
3-4,5	2.3	2.65	2.5
4,5-6	2,5	2,65	2,65
0-6	2,21	2,27	2,12

Regions: 1 - Transcarpathian trough, 2 - Folded Carpathians, 3 - Ciscarpathian basin , 4 - Volyno-Podolian plate, 5 - Ukrainian shield, 6 - Dnieper-Donets basin, 7 - Voronezh massif, 8 - Donbas, 9 - South-Ukrainian monoclinal ravine, 10 – Crimea

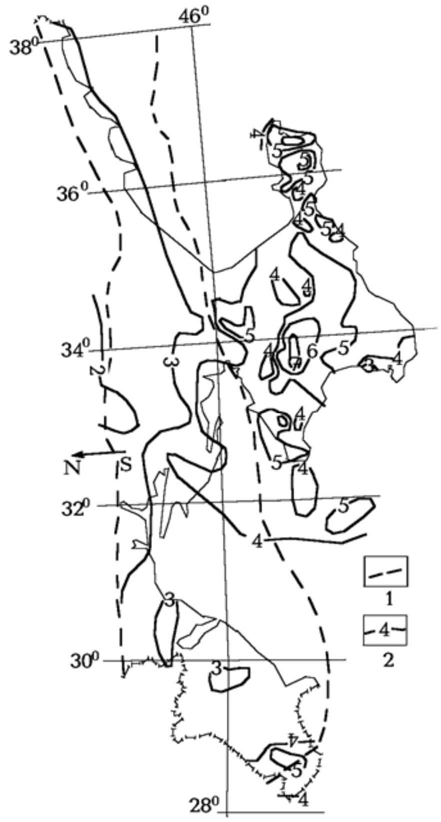


Figure 4. The results of W6 calculations in the Crimea and South-Ukrainian monocline 1 - borders of the region, 2 - isolinies of W

4. DISTRIBUTION OF GEOTHERMAL RESOURSES

The calculations of *W3*, *W4.5* and *W6* were carried out for drilling depths of 3, 4.5, and 6 km, respectively. The largest reserves were found for a borehole depth of 6 km. The values are shown in Figure 6. Commercial use of the energy is possible, as estimated in Tester (1990) when the geothermal gradient reaches 2.3 ºC/100 m. On the figures it matches 2.5 t.s.f. /m^2.

The total resources are about 0,8x10^{12} t.s.f.. The east area (Donbas and Dnieper-Donets basin) has total reserves value about 0,19x10^{12} t.s.f.. That is larger than the composite reserves of all of Ukraine mineral fuel: hard coal, lignite, oil and gas. The general reserves of all minerals fuels of the Ukraine are 0,04x10^{12} t.s.f. (Table 2.). Consequently, geothermal energy can be used virtually throughout the region.

The total reserves of the central part of Ukraine (Ukrainian Shield) with the density higher than 2,5 t.s.f./m^2 are 0,04x10^{12} t.s.f.. The western area (Carpathian region) has TR about 0,2x10^{12} t.s.f.. The southern area (Crimea and South-Ukrainian monocline) has total reserves about 0,3x10^{12} t.s.f..

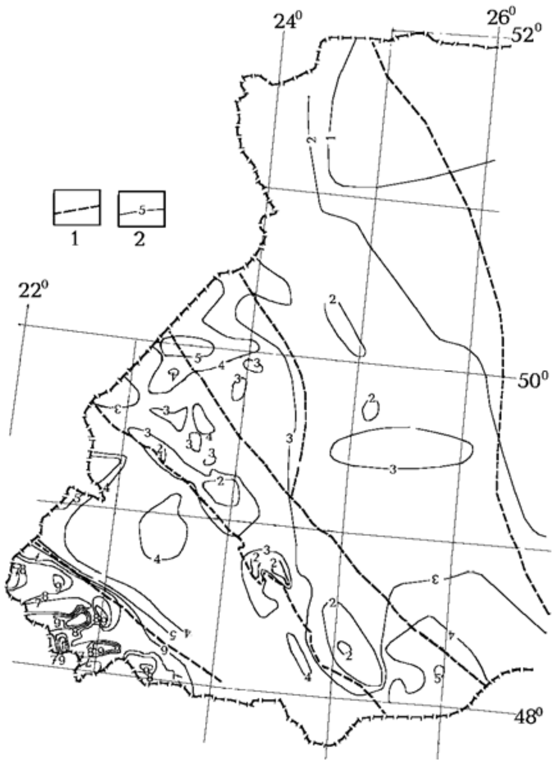
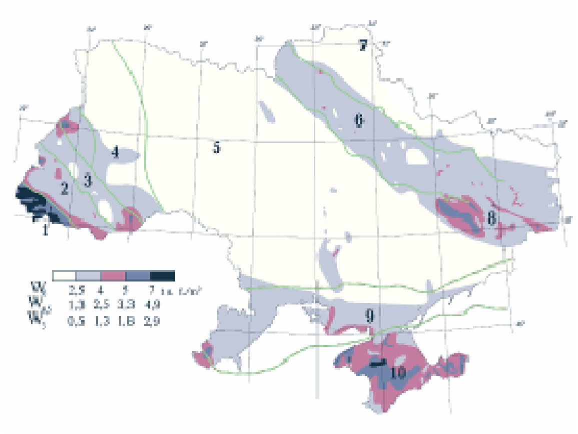


Figure 5. The result of the W6 calculations in the Carpathian region. 1 – border of region, 2 – isolines

Table 2.

Fuel	Deposits, t.s.f. (x10^{10})
Hard coal	3,880
Lignite	0,127
Peat	0,025
Oil	0,022
Gas	0,161
Condensate	0,012

Total	**4,000**



Regions: 1 - Transcarpathian trough, 2 - Folded Carpathians, 3 - Ciscarpathian basin , 4 – Volyn'-Podolia plate, 5 - Ukrainian shield, 6 - Dnieper-Donets basin, 7 - Voronezh massif, 8 - Donbas, 9 - South-Ukrainian monocline, 10 - Crimea

Figure 6. The distribution of W for drilling depths of 6, 4.5 and 3 km in the Ukraine

5. CONCLUSION

Ukraine is abundant in geothermal energy resources. Areas from low to medium-grade thermal reservoirs are very common. In some regions territories of different resources range were determined correctly, but for other ones we have no enough thermal data to draw a resource map.

The commercial exploration has outlooks and it needs high resolution maps of thermal resources of Ukraine. Somewhere thermal energy may be used for heating, somewhere for electricity production. In all regions (even in coal and gas basins) the thermal energy range is wider than the energy of all other resources.

The report uses results some of which have been obtained with the support from Ukraine's Fund for Fundamental Studies (grant 06.07/34).

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