Experimental studying the propagation and absorption of electromagnetic waves on various rock-forming minerals in Uzbekistan

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Abstract. The nature of wave propagation often depends on the frequency and on the type of radiation used. The main goal of these technologies is to bring into development low-permeability isolated zones of the reservoir by exposing them to elastic waves that attenuate in high-permeability sections of the reservoir, but propagate over considerable distances and with sufficient intensity to excite low-permeability sections of the reservoir. In this paper, a more in-depth study of the propagation and absorption of electromagnetic waves through various minerals contained in rock was considered, in particular, the behavior of electromagnetic waves through rock with different moisture contents (water molecules) and clay particles (aluminosilicates) was studied. It was found that the radiative power reached the highest value at 0.01 distance, which was 506 at 10% water content, followed by 505 at 20% water content, 504 at 30% water content, 502 at 40% water content, 500 at 50% water content, and it was 498 when water content was 60%.

Keywords: propagation, absorption, electromagnetic waves, rock, minerals, Uzbekistan

1. Introduction

One of the most important aspects of studying the application of wave technologies is the study of the behavior and nature of the propagation of waves through various materials [1-4]. The nature of wave propagation often depends on the frequency and on the type of radiation used. The type of radiation directly affects the nature of wave propagation through the rock [5]. Depending on the type of radiation and the frequency of the emitted object, the following types of wave technologies are distinguished: 1-acoustic, ultrasonic; 2-shock-wave; 3-vibroseismic; 4-high-frequency electromagnetic [6].

The main goal of these technologies is to bring into development low-permeability isolated zones of the reservoir by exposing them to elastic waves that attenuate in high-permeability sections of the reservoir, but propagate over considerable distances and with sufficient intensity to excite low-permeability sections of the reservoir [7]. When developing oil and gas fields, there is always such a negative manifestation as the formation of a cone of water near wells. When the formation water moves into the drainage zone and its adhesion with the rock, the water saturation increases and, accordingly, the phase permeability for water increases. At the same time, due to a decrease in the gas saturation of the reservoir and the phase permeability of the gas, the gas stops moving to the bottom of the well. The formation gas pressure in the pinched volume becomes insufficient to move it through the formed water...
barrier and the well stops producing useful products [8]. A distinctive feature of the use of electromagnetic waves is the deep penetration and minimal absorption by the porous medium and phases located inside the pore space.

Back in the 80s of the last century, studies of the influence of electromagnetic waves on oil and gas reservoirs were started in the Soviet Union, but due to the insufficient development of the technology for manufacturing emitter devices, ineffective results were obtained along with the impossibility of lowering equipment directly into the bottomhole zone of wells [9]. Usually in such cases, sidetracks are cut in the wells or special screens are created that prevent the inflow of formation water or other technologies are used, after which the inflow is caused by replacing the liquid with a lighter one (the method of lightening the liquid column) or with pumping (the method of lowering the liquid level), which lead to a decrease in pressure at the bottom of wells and drawdown was created [10].

The proposed technology is unique in that the microwave will be used for the first time in solving the problem of eliminating the water barrier in the CCD, which will quickly restore wells for gas production. All studies were aimed at studying the nature of wave propagation depending on various factors, such as the geometric dimensions and shapes of the emitter affect the propagation of waves [4, 6-8], and also studied the absorption and reflection of electromagnetic waves through various materials.

In this paper, a more in-depth study of the propagation and absorption of electromagnetic waves through various minerals contained in rock was considered, in particular, the behavior of electromagnetic waves through rock with different moisture contents (water molecules) and clay particles (aluminosilicates) was studied in more detail [1].

2. Methods

For the experiment, bulk models of the formation with different clay content were constructed (Figure 1). In total, 5 models were built with a clay content from 0 to 5% (0; 1; 3; 4; 5%) and in each, the moisture content was gradually increased from 0 to 60% [5-7].

At the same time, to determine the beginning of the impact front, a minimum power of at least 100 W was taken. Bulk models (V20;G0), (V10;G1), (V10;G1) showed close values. The minimum excitatory power reaches a distance of up to 1 meter (105mm). Bulk models (V20; G1), (V30; G0),
(V40; G0), (V30; G3), (V40; G4), (V60; G0) the minimum excitatory power reaches a distance of up to 30 cm. The remaining models have a more absorbable capacity than the above models [2, 4-5].

3. Results and Discussions
Taking into account the design features and the radius of the wells, it can be noted that in bulk models (of the second type), the use of radiation up to 100 W was ineffective. The electrical double layer between water and oil was a kind of reflective mirror for electromagnetic waves.

This allowed the waves to dissipate more evenly and reach resonant frequencies. Most of the electromagnetic waves, according to experiments, it became clear that they were absorbed by water-containing parts and aluminosilicates. At the same time, the iron-bearing parts of the rock prevent the propagation of electromagnetic waves, reflecting the moving wave front, which is recorded by detectors, thanks to which it is possible to build the geometry and nature of propagation (Figure 2).

Table 1 showed the results of electromagnetic radiation experiments at a nominal power of 710 W, while the main front of action ended in the range from 2.5 to 8 meters, depending on the saturation of the rock with moisture and aluminosilicates.

At the same time, it should be noted that on bulk models (V60; G5), (V50; G5) with a high content of aluminosilicates, it was necessary to use only radiation with minimum power amplitudes of more than 250W. The main exposure front of electromagnetic waves on average has a rated power of 400 to 550 watts. As can be seen from Figure 2 and Tables 2 and 3, it can be noted that the main impact front was located from 1.3 to 5.5 meters from the emitter. When the radiation power was reduced to 250W, there was a decrease in the radius of the exposure front from 1 to 2 meters, the results of which are shown in Table 4. As can be seen in Table 5, when the rated power is reduced to 150W, a significant decrease in the front radius can be seen to 1.5 meters from the source. These indicators of penetration depth are based on studies aimed at studying the absorbed and reflecting abilities of materials and minerals. The main disadvantage of using this technology was low energy efficiency. That was due to the lack of development in this area of technology. To date, the main directions for development in the field of operation of the emitter must be directed to radiation and improving the insulation of the generator, reducing its dimensions and solving the problem associated with temperature, since the maximum allowable temperature for the operation of the electromagnetic emitter generator was up to 65 °C.
Table 1. Measurement of the dependence of the radiated power on water cut, clay content and distance at a rated power of 710 W.

| Water cut % | 10 | 20 | 30 | 40 | 50 | 60 |
|-------------|----|----|----|----|----|----|
| Clay content | 0  | 0  | 0  | 0  | 0  | 0  |
| Distance, m | 0.01 | 709 | 708 | 707 | 706 | 704 | 701 |
|             | 0.5  | 693 | 688 | 680 | 669 | 655 | 638 |
|             | 1    | 650 | 644 | 633 | 617 | 597 | 573 |
|             | 1.5  | 591 | 583 | 569 | 550 | 526 | 496 |
|             | 2    | 524 | 514 | 499 | 477 | 448 | 414 |
|             | 2.5  | 457 | 446 | 429 | 404 | 373 | 334 |
|             | 3    | 395 | 383 | 364 | 337 | 303 | 261 |
|             | 3.5  | 340 | 328 | 307 | 278 | 241 | 195 |
|             | 4    | 293 | 280 | 258 | 227 | 187 | 138 |
|             | 4.5  | 253 | 239 | 215 | 182 | 140 | 88  |
|             | 5    | 219 | 204 | 180 | 145 | 100 | 46  |
|             | 5.5  | 191 | 175 | 149 | 113 | 66  | 9   |
|             | 6    | 167 | 151 | 124 | 85  | 37  |
|             | 6.5  | 147 | 130 | 101 | 62  | 11  |
|             | 7    | 130 | 112 | 83  | 42  |
|             | 7.5  | 115 | 97  | 66  | 24  |
|             | 8    | 102 | 83  | 52  | 8   |
|             | 8.5  | 91  | 72  | 40  |
|             | 9    | 82  | 62  | 29  |
|             | 9.5  | 74  | 53  | 19  |
|             | 10   | 66  | 45  | 10  |

According to Table 2, when the distance was 0.01, the radiative power was 709 at 10% water content, followed by 708 at 20% water content, 707 at 30% water content, 706 at 40% water content, and it was 704 and 701 at 50 and 60% water content, respectively. The lowest value of the radiative power was observed in 10 m distance, accounted for 66, 45 and 10 at 10, 20, 30% of water content, correspondingly.

Table 2. Measurement of the dependence of the radiated power on water cut, clay content and distance at a rated power of 710 W (continuation).

| Water cut % | 10 | 20 | 30 | 40 | 50 | 60 |
|-------------|----|----|----|----|----|----|
| Clay content | 1  | 1  | 3  | 4  | 5  | 5  |
| Distance, m | 0.01 | 709 | 708 | 705 | 702 | 698 | 694 |
|             | 0.5  | 691 | 685 | 665 | 642 | 613 | 589 |
|             | 1    | 648 | 639 | 611 | 579 | 538 | 503 |
|             | 1.5  | 588 | 577 | 543 | 503 | 453 | 411 |
|             | 2    | 520 | 508 | 468 | 423 | 364 | 316 |
|             | 2.5  | 453 | 439 | 395 | 344 | 278 | 224 |
|             | 3    | 391 | 376 | 327 | 271 | 199 | 140 |
|             | 3.5  | 336 | 320 | 267 | 207 | 129 | 65  |
|             | 4    | 288 | 271 | 215 | 150 | 67  |
|             | 4.5  | 248 | 230 | 170 | 102 | 14  |
However, that figure was very different when clay content had differentiated value. Clearly, the highest value of the radiative power was a bit different when containing 50% water and 5% clay, and 60% water and 5% clay, accounted for 698 and 964, respectively. The lowest values were reported when containing 30% water and 3% clay as well as at 50% water content and 5% clay, which were 8 and 14, correspondingly.

It was found that the radiative power reached the highest value at 0.01 distance, which was 506 at 10% water content, followed by 505 at 20% water content, 504 at 30% water content, 502 at 40% water content, 500 at 50% water content, and it was 498 when water content was 60% (Table 3). In this case, clay content was considered as 0. When the distance was 10, the radiative power reached the lowest value at 10 m and 20% water contents, which was 34 and 13, respectively.

Table 3. Measurement of the dependence of the radiated power on the water content, clay content and distance at a rated power of 510W.

| Water content | 10  | 20  | 30  | 40  | 50  | 60  |
|---------------|-----|-----|-----|-----|-----|-----|
| Clay content  | 0   | 0   | 0   | 0   | 0   | 0   |
| Distance, m   |     |     |     |     |     |     |
| 0.01          | 506 | 505 | 504 | 502 | 500 | 498 |
| 0             | 490 | 486 | 478 | 467 | 453 | 435 |
| 1             | 452 | 446 | 434 | 419 | 399 | 375 |
| 1.5           | 400 | 392 | 379 | 360 | 335 | 305 |
| 2             | 345 | 336 | 320 | 298 | 270 | 235 |
| 2.5           | 293 | 282 | 265 | 240 | 209 | 170 |
| 3             | 247 | 235 | 216 | 189 | 155 | 112 |
| 3.5           | 208 | 195 | 175 | 146 | 108 | 63  |
| 4             | 176 | 162 | 140 | 109 | 69  | 20  |
| 4.5           | 149 | 135 | 111 | 78  | 36  |     |
| 5             | 127 | 112 | 88  | 53  | 8   |     |
| 5.5           | 109 | 94  | 68  | 31  |     |     |
| 6             | 94  | 78  | 51  | 13  |     |     |
| 6.5           | 82  | 65  | 37  |     |     |     |
| 7             | 71  | 54  | 25  |     |     |     |
| 7.5           | 63  | 44  | 14  |     |     |     |
| 8             | 55  | 36  | 5   |     |     |     |
| 8.5           | 49  | 29  |     |     |     |     |
| 9             | 43  | 23  |     |     |     |     |
| 9.5           | 38  | 18  |     |     |     |     |
| 10            | 34  | 13  |     |     |     |     |
Furthermore, clay contents were from 1% to 5% at 10% to 60% water content, accordingly, the highest value was observed when the distance was 0.01, which was 505 and 491 at 10% and 60% water content. The lowest value of radiative power was determined when the distance was 9.5, accounted for 4. But it was 27, when containing 10% water and 1% clay (Table 4).

Table 4. Measurement of the dependence of the radiated power on the water content, clay content and distance at a rated power of 510W (continuation).

| Water cut % | 10 | 20 | 30 | 40 | 50 | 60 |
|-------------|----|----|----|----|----|----|
| Clay content | 1  | 1  | 3  | 4  | 5  | 5  |
| Distance, m |     |    |    |    |    |    |
|             | 0.01 | 505 | 504 | 502 | 498 | 494 | 491 |
|             | 0.5  | 489 | 483 | 463 | 440 | 411 | 386 |
|             | 1    | 450 | 441 | 413 | 381 | 339 | 305 |
|             | 1.5  | 398 | 387 | 352 | 313 | 262 | 220 |
|             | 2    | 342 | 330 | 290 | 244 | 186 | 137 |
|             | 2.5  | 289 | 275 | 231 | 180 | 114 | 60  |
|             | 3    | 243 | 228 | 179 | 123 | 51  |     |
|             | 3.5  | 203 | 187 | 135 | 74  |     |     |
|             | 4    | 171 | 154 | 97  | 33  |     |     |
|             | 4.5  | 144 | 126 | 66  |     |     |     |
|             | 5    | 122 | 103 | 40  |     |     |     |
|             | 5.5  | 104 | 83  | 17  |     |     |     |
|             | 6    | 88  | 67  |     |     |     |     |
|             | 6.5  | 76  | 54  |     |     |     |     |
|             | 7    | 65  | 42  |     |     |     |     |
|             | 7.5  | 56  | 33  |     |     |     |     |
|             | 8    | 48  | 24  |     |     |     |     |
|             | 8.5  | 42  | 17  |     |     |     |     |
|             | 9    | 36  | 10  |     |     |     |     |
|             | 9.5  | 31  | 4   |     |     |     |     |
|             | 10   | 27  |     |     |     |     |     |

It can be seen that when the rated power was 350W, the dependence of radiative power was a bit lower than the above results. At 0.01 distance, it was 347 at 10% water content, followed by 347 at 20% water, 345 at 30% water, 344 at 40% water, and it was 342 and 339 at 50% and 60% water content. According to the pertinent results, the lowest indicator was 1 at 20% water when the distance was 9 m, whereas it was 16 at 10% when the distance 10 m (Table 5).

Table 5. Measurement of the dependence of radiated power on water cut, clay content and distance at a rated power of 350W.

| Water cut % | 10 | 20 | 30 | 40 | 50 | 60 |
|-------------|----|----|----|----|----|----|
| Clay content | 0  | 0  | 0  | 0  | 0  | 0  |
| Distance, m |     |    |    |    |    |    |
|             | 0.01 | 347 | 347 | 345 | 344 | 342 | 339 |
|             | 0.5  | 334 | 329 | 321 | 310 | 296 | 279 |
|             | 1    | 302 | 295 | 284 | 269 | 249 | 225 |
It was found that the dependency of radiative power reached the highest value at 0.01 m distance, which was 347 at 10% water content, followed by 346 at 20% water content, 343 at 30% water content, 340 at 40% water content, 336 at 50% water content, and it was 332 when water content was 60%. In this case, clay content was considered as 0. When the distance was 10 m, the radiative power reached the lowest value at 10 % water contents, which was 8 (Table 6).

Table 6. Measurement of the dependence of radiated power on water cut, clay content and distance at a rated power of 350W (continuation).

| Water cut % | 10  | 20  | 30  | 40  | 50  | 60  |
|-------------|-----|-----|-----|-----|-----|-----|
| Clay content | 1   | 1   | 3   | 4   | 5   | 5   |
| Distance    | when containing 10% water and 1% clay | when containing 20% water and 1% clay | when containing 30% water and 3% clay | when containing 40% water and 4% clay | when containing 50% water and 5% clay | when containing 60% water and 5% clay |
| 0.01        | 347 | 346 | 343 | 340 | 336 | 332 |
| 0.5         | 332 | 326 | 306 | 283 | 254 | 230 |
| 1           | 300 | 291 | 263 | 231 | 189 | 155 |
| 1.5         | 258 | 247 | 213 | 173 | 123 | 81  |
| 2           | 215 | 203 | 163 | 118 | 59  | 11  |
| 2.5         | 177 | 163 | 119 | 68  | 2   |     |
| 3           | 145 | 130 | 81  | 25  |     |     |
| 3.5         | 118 | 102 | 50  |     |     |     |
| 4           | 97  | 80  | 24  |     |     |     |
| 4.5         | 80  | 62  | 2   |     |     |     |
| 5           | 66  | 47  |     |     |     |     |
| 5.5         | 55  | 35  |     |     |     |     |
| 6           | 46  | 25  |     |     |     |     |
| 6.5         | 38  | 16  |     |     |     |     |
| 7           | 32  | 9   |     |     |     |     |
| 7.5         | 26  | 3   |     |     |     |     |
| 8           | 22  |     |     |     |     |     |
| 8.5         | 18  |     |     |     |     |     |
| 9           | 14  |     |     |     |     |     |
| 9.5         | 11  |     |     |     |     |     |
| 10          | 8   |     |     |     |     |     |
However, the lowest value for the dependency of the radiative power on water and clay was observed at 4 and 4.5 m distance, which was 2 for both distances at 30 % water and 3% clay, and 50% water and 5% clay, respectively.

According to Table 7, when the rated power was 250W, at 0.01 m distance, the radiative power was 246 at 10% water content, followed by 245 at 20% water content, 244 at 30% water content, 243 at 40% water content, and it was 241 and 238 at 50 and 60% water content, respectively. The lowest value of the radiative power was observed in 10 m distance, accounted for 7 at 10% water content. Among them, the lowest value was reported at 20% and 30 % water content, which was 3 at 7 and 5 m distance, correspondingly.

Table 7. Measurement of the dependence of radiated power on water cut, clay content and distance at a rated power of 250W.

| Water cut % | 10 | 20 | 30 | 40 | 50 | 60 |
|-------------|----|----|----|----|----|----|
| Clay content | 0  | 0  | 0  | 0  | 0  | 0  |

| Distance | at 10% water content | at 20% water content | at 30% water content | at 40% water content | at 50% water content | at 60% water content |
|----------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| 0.01     | 246                  | 245                  | 244                  | 243                  | 241                  | 238                  |
| 0.5      | 235                  | 230                  | 222                  | 211                  | 197                  | 180                  |
| 1        | 209                  | 202                  | 191                  | 176                  | 156                  | 131                  |
| 1.5      | 176                  | 168                  | 155                  | 136                  | 111                  | 81                   |
| 2        | 145                  | 135                  | 120                  | 98                   | 69                   | 35                   |
| 2.5      | 117                  | 107                  | 89                   | 65                   | 33                   |                      |
| 3        | 95                   | 83                   | 64                   | 37                   | 3                    |                      |
| 3.5      | 77                   | 64                   | 44                   | 15                   |                      |                      |
| 4        | 63                   | 49                   | 27                   |                      |                      |                      |
| 4.5      | 52                   | 38                   | 14                   |                      |                      |                      |
| 5        | 43                   | 28                   | 3                    |                      |                      |                      |
| 5.5      | 36                   | 20                   |                      |                      |                      |                      |
| 6        | 30                   | 13                   |                      |                      |                      |                      |
| 6.5      | 25                   | 8                    |                      |                      |                      |                      |
| 7        | 21                   | 3                    |                      |                      |                      |                      |
| 7.5      | 18                   |                      |                      |                      |                      |                      |
| 8        | 15                   |                      |                      |                      |                      |                      |
| 8.5      | 12                   |                      |                      |                      |                      |                      |
| 9        | 10                   |                      |                      |                      |                      |                      |
| 9.5      | 9                    |                      |                      |                      |                      |                      |
| 10       | 7                    |                      |                      |                      |                      |                      |

Table 8 showed that clay content was 1, 3, 4, and 5 while water content was distinguished at 10% to 60. The highest results were observed at 0.01 m distance, which were 246 at 10% water and 1% clay, followed by 245 at 20% water and 1% clay, 242 at 30% water and 4% clay, 235 at 50% water and 5% clay, and it was 231 when containing 60% water and 5% clay. The lowest value was report at 9.5 m distance, which was 1 when containing 10% water and 1% clay.

Table 8. Measurement of the dependence of radiated power on water cut, clay content and distance at a rated power of 250W (continuation).
When the rated power was 150W, the dependency of the radiative power on water cut and clay content was high at 0.01 distance, which was 158 at 10% water, followed by 158 at 20% water, 157 at 30% water, 155 at 40% water, and it was 153 and 151 when containing 50% and 60% water. The lowest value of the dependency was 1 at 10 m distance, particularly at 10% water, while at 20% it was 2 at 5.5 distance (Table 9).

Table 9. Measurement of the dependence of radiated power on water cut, clay content and distance at a rated power of 150W.
The highest value for the dependency of the radiative power was observed at 0.01 distance, which was 158 when containing 10% water and 1% clay, meanwhile it was 3 at 7 m distance, especially when water and clay were 10% and 1%, correspondingly (Table 10).

Table 10. Measurement of the dependence of radiated power on water cut, clay content and distance at a rated power of 150W (continuation).

| Water cut % | 10 | 20 | 30 | 40 | 50 | 60 |
|-------------|----|----|----|----|----|----|
| Clay content | 1 | 1 | 3 | 4 | 5 | 5 |
| Distance | when containing 10% water and 1% clay | at 20% water and 1% clay | at 30% water and 3% clay | at 40% water and 4% clay | when containing 50% water and 5% clay | when containing 60% water and 5% clay |
| 0.01 | 158 | 157 | 154 | 151 | 147 | 144 |
| 0.5 | 148 | 142 | 122 | 99 | 70 | 46 |
| 1 | 128 | 119 | 91 | 59 | 17 | |
| 1.5 | 104 | 93 | 59 | 20 | | |
| 2 | 82 | 70 | 30 | | | |
| 2.5 | 64 | 50 | 5 | | | |
| 3 | 49 | 34 | | | | |
| 3.5 | 38 | 22 | | | | |
| 4 | 29 | 12 | | | | |
| 4.5 | 22 | 4 | | | | |
| 5 | 16 | | | | | |
| 5.5 | 12 | | | | | |
| 6 | 8 | | | | | |
| 6.5 | 5 | | | | | |
| 7 | 3 | | | | | |
| 7.5 | 0 | | | | | |
| 8 | | | | | | |
| 8.5 | | | | | | |
| 9 | | | | | | |
| 9.5 | | | | | | |
| 10 | | | | | | |

4. Conclusions
1. According to Table 1, when the distance was 0.01, the radiative power was 709 at 10% water content, followed by 708 at 20% water content, 707 at 30% water content, 706 at 40% water content, and it was 704 and 701 at 50 and 60% water content, respectively.
2. When the rated power was 250W, at 0.01 distance, the radiative power was 246 at 10% water content, followed by 245 at 20% water content, 244 at 30% water content, 243 at 40% water content, and it was 241 and 238 at 50 and 60% water content, respectively. The lowest value of the radiative power was observed in 10 m distance, accounted for 7 at 10% water content. Among them, the lowest value was reported at 20% and 30 % water content, which was 3 at 7 and 5 distance, correspondingly.
3. It should be noted that on bulk models (V60; G5), (V50; G5) with a high content of aluminosilicates, it was necessary to use only radiation with minimum power amplitudes of more than 250W.

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