ELECTROMAGNETIC AND ACOUSTIC ACTION ON A SATURATED POROUS MEDIUM

F. L. Sayakhov, V. P. Dyblenko,
I. A. Tufanov, O. L. Kuznetsov,
É. M. Simkin, and S. A. Efimova

UDC 538.569:534.29

The results are presented of an experimental study concerning the effect of sound on high-frequency heating of a bituminous bed model.

Several studies [1-3] have dealt with intensification of heat and mass transfer processes in saturated porous media by simultaneous action of heat and sound.

Intensification of heat and mass transfer in saturated porous media by an acoustic field was in those studies attributed to a manifold increase of the thermal diffusivity of the material and to various diffusion-filtration effects induced in it. Dissipation of the energy of a strong high-frequency electromagnetic field in the medium gives rise to a thermal field with a space–time temperature distribution which depends rather weakly on the thermophysical properties of the material but is determined mainly by the distribution of the electromagnetic field and on the electrical properties of the material. An appreciable change in the thermal diffusivity caused by an acoustic field should, however, produce changes in the temperature field.

For an experimental study of these phenomena, an apparatus was built (Fig. 1) making it possible to examine the thermal effects in a saturated porous medium due to the simultaneous presence of a high-frequency electromagnetic field and an acoustic field.

The apparatus included a triple-layer model of a bed, a well through it with an acoustic radiator and an electromagnetic radiator inside, also a model GUZ-1.5N ultrasonic oscillator (or model GZ-34 with a model TU-600 amplifier) and a model VChD-2.5 electromagnetic high-frequency oscillator above ground. The bed model comprised a lump of natural bituminous Shugorov sandstone, 0.70 m thick and 60 cm in diameter, between 0.15-m-thick layers of moist clay and enclosed inside a wooden box 1.40 × 1.40 × 1.40 m large. The productive bed material was separated from the surrounding box by quartz sand of the 0.1-0.4 mm fraction. A dielectric tube 4.2 cm in diameter was inserted into the bed model along the axis of the latter.

One of the main components of the apparatus was technological equipment for simultaneously transmitting the energy of the electromagnetic field and of the acoustic field to the bed. This is achieved by two radiators (an electromagnetic one and an acoustic one) inside the well.

The electromagnetic high-frequency radiator constituted a part of the inner tube projecting below the outer tube (drive pipe), as shown in Fig. 1. For proper centering and prevention of closure, the tubes were separated by Teflon washers. The radiators received excitation from a coupling capacitor.

As the source of acoustic waves served a chain of 10 cylindrical TsTS-19 piezoceramic transducers, joined by means of Teflon sleeves, placed inside the electromagnetic radiator so as to be found within the middle portion of the productive bed.

The supply leads to the acoustic radiator were passed through the inner tube outside. Pickup along the supply leads to the acoustic radiator from the electromagnetic high-frequency oscillator during operation of the latter was suppressed by means of a high-frequency filter in the lead circuit. Acoustic contact was ensured by filling the well with transformer oil.

The temperature at various points of the bed was measured with copper-Constantan thermocouples located within the middle portion of the bed and enclosed inside porcelain insulator tubes. The frequency and the intensity of acoustic radiation was recorded by TsTS-12 piezoceramic probes placed inside the dielectric tubes

---

"Fourtieth Anniversary of October" Bashkir State University, Ufa. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 36, No. 4, pp. 648-652, April, 1979. Original article submitted February 21, 1978.

0022-0841/79/3604-0428$07.50

TABLE 1. Temperature (°C) Distribution in the Model of Charge

Frequency, kHz	Time, h	Distance from the well R, cm			
		4	14	21	37
6	0	25	25	25	25
	3	31	25	25	25
	5	31	25	25	25
	8	31,5	25	25	25
16	0	27	27	27	27
	3	37,5	28	27	27
	5	40	30	27	27
	8	42,5	30,5	27	27

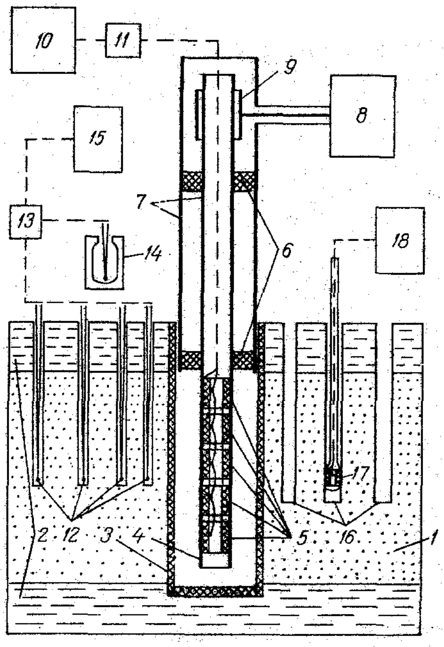

Fig. 1. Schematic diagram of the experimental apparatus: 1) bitumen bed; 2) roof and floor of the bed; 3) dielectric tube; 4) radiator of high-frequency electromagnetic energy; 5) radiator of acoustic energy; 6) dielectric washers; 7) aluminum tubes; 8) model VChD-2.5/13 electromagnetic high-frequency oscillator; 9) coupling capacitor; 10) model GUZ-1.5N ultrasonic oscillator (or model GZ-34 with a model TU-600 amplifier); 11) high-frequency filter; 12) thermocouples; 13) multicontactor switch; 14) Dewar flask; 15) model V2-15 microvoltmeter; 16) dielectric tubes; 17) acoustic receivers; 18) model S1-19A oscillograph.

containing transformer oil, and connected to the model S1-19A oscillograph. The thermocouples were connected to the model V2-15 microvoltmeter through a multicontactor switch.

The productive bed had the following characteristics: bitumen content 10 wt.% water saturation 0.5, porosity 40 wt.%, dielectric constant 7.6, and dielectric loss tangent 0.15 (at a 13-MHz frequency). The saturating bitumen was of the maltha grade, with a density of 1024 kg/m^3 and a viscosity of 630 kg/m · sec at 25°C. The experimental procedure was as follows.

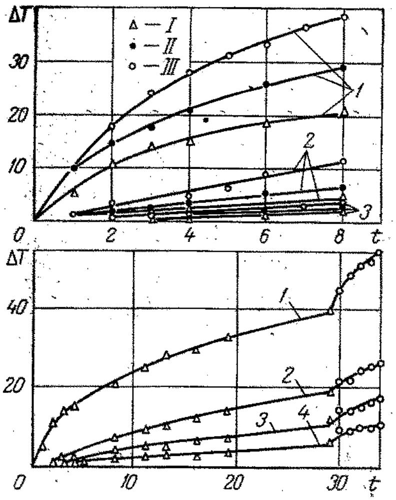

Fig. 2

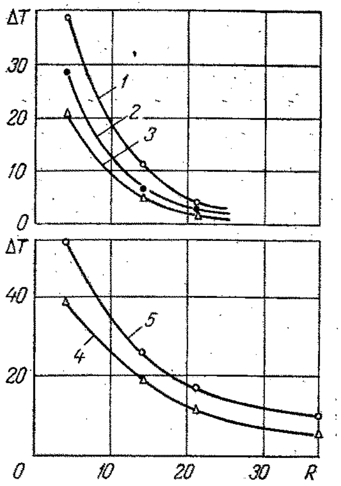

Fig. 3

Fig. 2. Dependence of the temperature on the heating time: I) electromagnetic high-frequency heating, II) and III) electromagnetic high-frequency heating in an acoustic field of frequencies 6 and 16 kHz respectively; 1) R = 4 cm, 2) R = 14 cm, 3) R = 21 cm, 4) R = 21 cm.

Fig. 3. Temperature distribution as a function of the distance: 1, 2, 3) t = 8 h, 4) 29 h, 5) 34 h (5 h of electromagnetic-acoustic treatment). Legend of experimental points the same as in Fig. 2.

1. Recording the space–time temperature distribution in the bed model electromagnetically heated with a power of 0.5 kW at a frequency of 13.56 MHz.

2. Performing analogous measurements during simultaneous electromagnetic heating with the same power at the same frequency and acoustic treatment with an intensity of 0.9 W/cm^2 at frequencies of 16 and 6 kHz respectively.

3. Performing analogous measurements during acoustic treatment alone, with the same intensity and at the same frequency.

The temperature could not be measured during operation of the electromagnetic high-frequency oscillator, because of large pickup voltages induced in the thermocouple wires by the electromagnetic high-frequency field. For this reason, the oscillator was turned off for the duration of measurements. Inasmuch as the measurements were made quickly (they took not more than 2 min each), shutdown of the oscillator did not affect the thermal field of the bed.

Altogether 15 experiments were performed. The results of these experiments are given in Table 1 and Figs. 2-3.

According to the data in Table 1, the results of an 8-hour acoustic treatment (at 6 and 16 kHz respectively) of the bituminous bed, heating of the acoustic radiator affected the temperature distribution in the bed only at distances from the well equal to 4 cm (f = 6 kHz) or 4 and 14 cm (f = 16 kHz). No temperature rise was noted at other points in the bed.

The graphs in Figs. 2 and 3 indicate that acoustic treatment increases the effectiveness of electromagnetic high-frequency heating of a bituminous bed. The rate of electromagnetic high-frequency heating becomes faster in an acoustic field (Fig. 2). The heating rate increases with increasing frequency of the acoustic field.

The space distribution of the temperature shown in Fig. 3 reveals a deeper penetration of electromagnetic high-frequency heating of a bituminous bed in an acoustic field. Moreover, the penetration was deeper at 16 kHz than at 6 kHz with the same intensity of the acoustic field.

Also interesting are the results of experiments (Figs. 2 and 3) with electromagnetic high-frequency heating and delayed acoustic treatment ($f = 16$ kHz). According to the graphs here, the heating rate increased sharply immediately after the acoustic field had been turned on. The rate of increase depended on the distance from the acoustic radiator and from the electromagnetic high-frequency radiator.

These changes in the space–time distribution of the temperature in our model of a bituminous bed can be explained by an increase in the thermal diffusivity of sandstone due to acoustic treatment. As a consequence, the electromagnetic high-frequency heating depends more strongly on the thermal diffusivity and contributes more to the temperature distribution during high-frequency heating.

One must also consider a possible contribution to the intensification of high-frequency heating by a combination of lower viscosity of heated bitumen in an acoustic field and filtration flow due to an acoustic-pulse pressure drop.

NOTATION

f (kHz) is the frequency of the acoustic field;
ΔT (°C) is the temperature rise;
t is the time;
t_{ac} is the time of turning on the acoustic field;
R (cm) is the distance from the wall.

LITERATURE CITED

1. E. V. Karus, O. L. Kuznetsov, et al., "Effect of acoustic treatment on heat and mass transfer in saturated, porous, and colloidal media," Dokl. Akad. Nauk SSSR, 218, No. 6 (1974).
2. M. L. Surguchev, O. L. Kuznetzov, and É. M. Simkin, Hydrodynamic, Acoustic, and Thermal Cyclic Treatment of Petroleum Beds [in Russian], Izd. Nedra, Moscow (1975).
3. É. M. Simkin, O. L. Kuznetsov, and E. E. Filatova, "Experimental study of heat conduction in saturated media during treatment with an acoustic field of various intensities," Inzh.-Fiz. Zh., 23, No. 6 (1972).

PERFORMANCE OF A HEAT-EXCHANGE TURBULIZER

Yu. G. Nazmeev and N. A. Nikolaev

UDC 536.24

Experimental evidence is surveyed for the performance of various types of turbulizers in convective heat transfer. An optimum range in Reynolds number and optimum ranges of geometrical parameters are identified.

There are two major ways of accelerating heat transfer in tubes; the first involves producing spiralling with strip and plate devices, which influence the entire flow. The second involves modifying the flow region near the wall by means of artificial roughnesses such as grooves on the inside wall, wire spirals, etc.

A large volume of experimental evidence has been accumulated on heat transfer in tubes with various devices covering wide ranges in heat load and physical parameters [1-15]. Some methods based on strip devices form the subject of interesting surveys [4, 16]. Table 1 gives the major results. No systematic survey has previously been published on the experimental data for the various types of systems in a form that could be used in comparative evaluation.

The ultimate purpose of any method of accelerating convective heat transfer is to provide a basis for designing equipment with the minimum transfer surface or minimum temperature difference subject to minimum power consumption in fluid pumping. Any of the methods of accelerating heat transfer increases the hydraulic resistance and thus increases the pumping power, so a major parameter must be the performance of the convecting surfaces. The following performance factor (the energy factor) is the one usually employed [2, 14, 17, 18]:

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 36, No. 4, pp. 653-657, April, 1979. Original article submitted May 22, 1978.

0022-0841/79/3604-0431$07.50