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ELECTRICAL PROCESSES
IN ENGINEERING AND CHEMISTRY

On Modeling of Processes of Moisture Circulation and Electric Charge Separation in the Atmosphere

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Abstract—The possibilities of obtaining water and electric energy from the atmosphere by means of simulation of the local atmospheric moisture cycle as well as electrical phenomena which accompany it in both natural and laboratory conditions are discussed. The basic possibility of achieving these goals according to the natural analogy is shown experimentally.

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INTRODUCTION

One of the most widespread natural atmospheric cycles is moisture circulation, which comprises the following sequence of thermodynamic processes: water evaporation from the Earth's surface, its rise in vapor form to upper colder strata of the atmosphere, vapor condensation in these strata and formation of clouds, and water falling on the Earth in the form of precipitation [1]. The whole cycle is more or less obviously accompanied by electrical phenomena caused by separation of electric charges and concluding with discharges in the form of various types of lightning and glows.

Study of these processes and phenomena in aggregate is of current interest, at least, for the following purposes: forecast and control of weather, and obtaining water and electric energy from the atmosphere; this is possible both directly from the natural phenomena themselves and from physicomathematical (theoretical) and/or experimental phenomena in natural or laboratory conditions.

At present, atmospheric processes are studied on a global scale by virtue of artificial satellites orbiting the Earth using computer modeling of relevant mathematical equations and their solutions. The results of these investigations are widely applied, in particular, for achieving the aforementioned goals, as well as in aviation, navigation, agriculture, etc.

As to the processes of obtaining water and electric energy, they require a local modeling of the atmospheric moisture circulation and atmospheric electricity accompanying it. The present work is devoted to such a modeling; for obtaining water from the atmosphere and soil, it is necessary to model the water cycle only.

EXPERIMENTAL

Moisture Circulation Modeling in Natural Conditions

Obtaining water for practical needs directly, i.e., for drinking, irrigation, etc., requires carrying out natural modeling, not laboratory modeling. The solution of this problem is stated in [2, 3] (first parts).

The solution of the problem consists in the following. On the slope of a hill, a so-called solar vapor collector (SVC) is built. It is, in essence, a hothouse located along the slope (see the schematic diagram in Fig. 1) in such a way that one of its edges is at the bottom of the slope, in warmer strata of the atmosphere, and the other is at the top of the slope, in colder strata. For this purpose, the hothouse (SVC) must be sufficiently long, on the order of tens or even hundreds of meters. Then the pressure difference due to corresponding differences of heights and temperatures, which would lead to movement of moist air upwards inside the SVC, may be appreciable.

There are two main requirements to the slope: it must be situated on the sunny side and be sufficiently moist; that is, the locality should be chosen near reservoirs, water springs, marshes, etc. Both of these requirements satisfy the condition for obtaining a sufficient amount of moist air in the hothouse. The moisture itself is formed in the result of its evaporation from soil at the base of the SVC (Fig. 1). As was already mentioned, a pressure difference appears at the ends; therefore, in the upper and lower parts of the SVC, adjustable windows for air going in and out are made. Thus, moisture can come to the collector from both the soil and the surrounding atmosphere.

Evaporation of moisture and its rise in vapor form are modeled in the SVC. The condensation process is realized in a vapor condenser (VC) specially built at the top of the SVC, where vapor condensation in clouds is modeled. The condenser is cooled from the outside

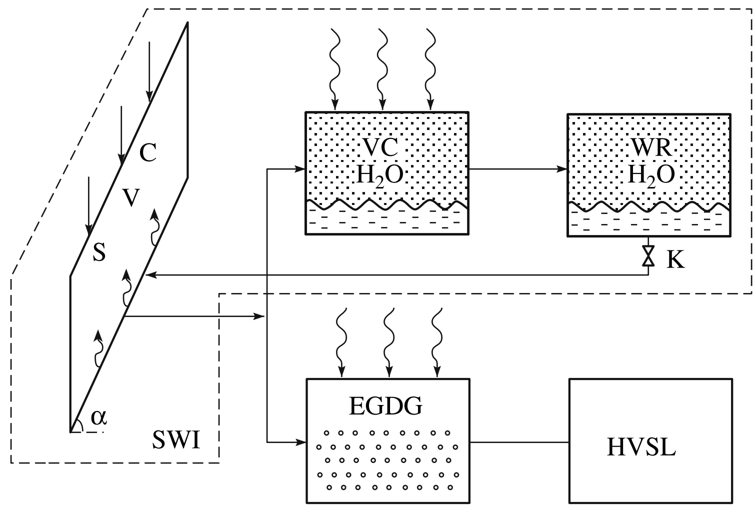

Fig. 1. Solar–wind energy complex. SVC is the solar vapor collector; VC is the vapor condenser; WR is the water reservoir; EGDG is the electrogasdynamic generator; HVSL is the high-voltage supply line; K is the faucet; ↓ is solar rays; ⟅ is wind; ↑ is vapor.

owing to wind; therefore, the solar collector combined with the condenser is called a solar–wind installation (SWI). Reverse motion of condensate from the VC to the collector through the faucet *K* would artificially simulate the natural cycle; however, for practical purposes, the condensate goes into a special water reservoir (WR). This completes the process of moisture circulation and its use in the solar–wind installation (Fig. 1).

Obtaining Electric Energy

For solution of the second problem, an electrogasdynamic generator (EGDG) is designed [2–4], a simplified calculation of which is given in [5].

The principle of operation of the EGDG is the following. There is a system of electrodes of the "needle–ring" type supplied with high dc voltage ($U \geq 2$–3 kV). As is known, in such a system, there appears a corona discharge [6] and, in turn, a unipolar space charge of sign of the corona electrode, the needle in our case. If wind blows on the corona system, the space charge is blown off to the side of the third counterelectrode–collector usually in the form of a metal net. Thus, the charge from the corona electrode is "pumped" to the counterelectrode, creating a potential difference preventing "pumping" of charges by wind. This difference is the emf of the EGDG.

However, in pure air, the effect of emf generation is weak owing to low windage, high mobility of air ions [7]; hence, it was proposed to use, as a working medium in the EGDG, a water aerosol [2, 3, 4, 7] obtained by mixing warm moist air from the SVC and cold surrounding wind (Fig. 1) supplied to the EGDG through a special branch pipe [2, 3]. In this case, the EGD effect increases significantly.

It seems to us that something of the kind takes place in atmospheric conditions; therefore, hypothetically, some aspects of the process of charge separation in clouds are modeled in the EGDG.

The solar–wind installation, shown inside the dotted line, and the EGDG form the solar–wind energy complex (SWEC). Practical realization of the given complex obviously requires additional experimental research under laboratory conditions.

Laboratory Modeling of Atmospheric Processes of Moisture Circulation and Charge Separation

Design features of the experimental complex and the physical processes taking place in it are described below; the basic results obtained are discussed as well.

Solar Vapor Collector

An experimental model of the SWI is presented in Fig. 2 showing a collector in the form of a gutter of length $l = 1.4$ m, width $b = 0.25$ m, and controllable height of moist air strata $0.02 \text{ m} \leq h \leq 0.15$ m. More than half of the gutter is filled with soil, mainly a mixture of sand and aglite, of thickness $H = 0.2$ m. In the middle of soil layer *1,* in the longitudinal direction, drainpipes *3* are installed for forwarding the obtained condensate back into the soil and simulation of a moisture circulation cycle. The gutter is covered with polyethylene film *2*.

An electric floodlight *S* simulated the Sun. The temperature on the surface of the soil and inside it was measured by means of thermocouple *7*. Window *9* served for regulation of external air forwarded to the SVC. In addition to height *h*, the angle of inclination to the horizon α was an adjustable parameter that could be varied within the range of $0° \leq \alpha \leq 45°$. The soil was moistened with water. The soil was heated by the floodlight; however, it appeared that such heating quickly, in about 30 min, led to drying of the soil surface and to a sharp

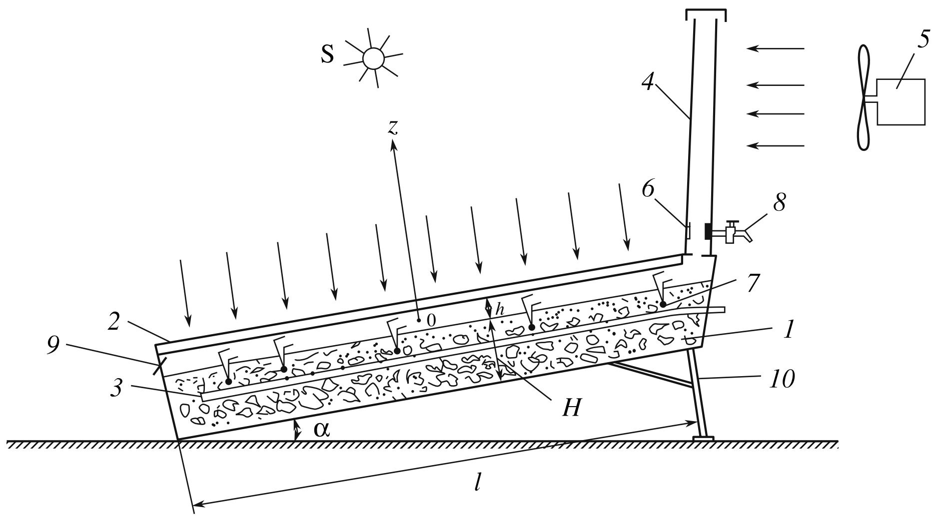

Fig. 2. Solar vapor collector: (*1*) soil; (*2*) film; (*3*) drainpipe; (*4*) condenser; (*5*) ventilator; (*6*) condensate; (*7*) thermocouple; (*8*) faucet; (*9*) window; (*10*) support.

decrease in vapor formation in the collector. Theoretical estimations have shown that, in natural conditions, the drying time is much greater ($\tau \sim 10$ h); therefore, heating by the floodlight did not simulate the natural process; we had to mount a wire heater in ceramic electrical insulation ~2–3 cm deep in the soil.

The problem of transport of moist air in the SVC in the laminar mode is solved in [8], where discharge of water in vapor form through the cross section of the SVC channel is expressed by the formula

$$G_v = \gamma b\left(\frac{s_0}{b}G + \frac{Ah^3 r_s}{120}\right), \quad (1)$$

where γ is the moist air density; s_0 is the average relative humidity of the air at the level $z = 0$ (Fig. 2); and G is its volume discharge, m^3/s, determined by the formula

$$G = b\int_{-h/2}^{h/2} v(z)dz = -\frac{\Delta P}{l}\frac{bh^3}{12\eta}, \quad (2)$$

where $\Delta P/l$ is the pressure drop along the channel of length l, and η is the dynamic coefficient of air viscosity. The parameter A characterizes the natural convection (NC) of combined origin (thermal $\beta\theta_s$ and moisture $\beta_s r_s$) and it is equal to

$$A \equiv \frac{g(\beta\theta_s + \beta_s r_s)\sin\alpha}{6\nu}, \quad (3)$$

where $\beta = -\frac{1}{\gamma_0}\left(\frac{\partial\gamma}{\partial T}\right)_0$; $\beta_s = -\frac{1}{\gamma_0}\left(\frac{\partial\gamma}{\partial s}\right)_0$; $\nu \equiv \eta/\gamma$;

and the differences of temperature θ_s and moisture r_s on the lower and upper bases of the stratum are given by the formulas

$$\theta_S \equiv T_2 - T_1 = T\left(-\frac{h}{2}\right) - T\left(\frac{h}{2}\right);$$
$$r_S \equiv S_2 - S_1 = S\left(-\frac{h}{2}\right) - S\left(\frac{h}{2}\right). \quad (4)$$

Formulas (1) and (2)–(4) give a complete physical picture of what must be done to increase the efficiency of the SVC.

Dwelling briefly on the physical aspects of formula (1), we should note that the first term describes the vapor flow caused by the unbalanced gradient of pressure $\Delta P/l$, for example, wind head; and if the channel is closed at the ends, then $G = 0$, and according to formula (1), the vapor mass transport is realized exclusively through NC,

$$G_v = \frac{\gamma g(\beta\theta_s + \beta_s r_s)bh^3 r_s \sin\alpha}{720\nu}, \quad (5)$$

and precisely the moisture factor ($r_s \neq 0$) leads to moisture transport ($G_v \neq 0$). The rate profile is cubic, $\nu \sim z^3$. In the case of an open channel, the cubic profile is superimposed by a parabolic quadratic one caused precisely by the pressure differential; however, under laboratory conditions with small l, the differential is low and we will neglect it at first, confining ourselves for calculations to formula (5). The convective moisture transport, in contrast to the hydrodynamic one ($\Delta P \neq 0$), is one of the peculiarities of the solar collector functioning under laboratory conditions.

Let us note that one-dimensional convective flow is unstable at the Grashof numbers

$$Gr \equiv \frac{g(\beta\theta_s + \beta_s r_s)h^3}{\nu^2}, \quad (6)$$

being close to the critical ones $Gr^* \leq 10^4$ and at $\alpha \sim 30°$ [9]. Assuming in (6) $\beta\theta_s + \beta_s r_s \sim 10^{-3}$ and $\nu \sim 10^{-4}$ m^2/s [10], we find the critical height $h_* \sim 20$ cm, above which the flow is reconstructed into a cellular one, that is, cells of the Benar type [10] rolling up and down in the longitudinal direction; upon a further increase in the Gr number, the flow becomes turbulent [9]. The critical values of h do not exceed tens of centimeters according to more accurate estimates. However, at first, as was already mentioned, we will confine ourselves to formula (5), which is justified under two conditions:

$$h < h_* \equiv \left(\frac{\nu^2 Gr^*}{g(\beta\theta_s + \beta_s r_s)}\right)^{1/3}, \quad (7)$$

$$h \ll b. \quad (8)$$

The second one is not connected with stability of motion, but is a condition of the plane-parallel flow. It goes without saying that, between two values of h satisfying jointly conditions (7) and (8), one should choose the smaller one.

Vapor Condenser

The flow of moist air from the collector comes to vapor condenser *4* (Fig. 2), which is a thin-walled metal cylinder having height $h_c = 880$ mm and diameter $d_c = 70$ mm. From the outside, air was blown on the condenser from a typical room ventilator, which not only simulated wind, but in fact cooled the condenser. It should be noted that cooling also occurred by natural convection.

The condensate discharge on the basis of [11] was determined by the generalized formula

$$\frac{G_C}{G_{CO}} = 5.88 \times 10^{-3} \Pi (Gr\Pr)^{0.25} \mathrm{Re}^{0.6}, \quad (9)$$

where G_{CO} is the vapor mass discharge at the condenser inlet; $\Pi \equiv \frac{\lambda\theta_0 S}{r d G_{co}}$; $\mathrm{Re} \equiv \frac{vd}{\nu}$; $\Pr \equiv v/a$; S is the lateral area of the condenser; d is the diameter; ν is the ventilator blow rate; and θ_0 is the difference of the temperatures of the condenser surface and the surrounding air.

Electrohydrodynamic Generator

The EGD generator designed for a natural energy system where aerosol was formed as a result of vapor mixing with cold air at the EGDG inlet was in a general outline described above. The first experiments with this method of obtaining aerosol showed insufficient efficiency of the EGDG operation; therefore, another variant was used where the corona electrode, in the form of a pinned spherical surface, was sprayed with water and simultaneously subjected to airflow. As a result, water dispersion took place owing to both electrostatic forces of repulsion and hydrodynamic factors. This is another peculiarity of the EGDG laboratory model.

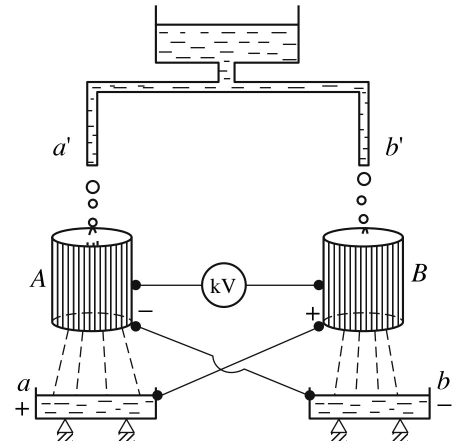

Fig. 3. Kelvin generator: *a*' and *b*' are the capillaries; *A* and *B* are the cylinder electrodes; *a* and *b* are the vessels for collection of charged water.

This method of obtaining a coarse dispersion working medium for the EGDG appeared to be more efficient, but it requires an autonomous source of high voltage for maintaining the corona discharge, which is absent or converted in natural conditions. Such a solution of the problem is necessary when electricity "just" appears; under laboratory conditions, it may be ingeniously solved by means of a Kelvin generator (KG), a schematic diagram of which is shown in Fig. 3.

The principle of its operation is the following. Let the first drop, e.g., the one which has fallen from the capillary *a*', have a random positive charge. This charge, flowing into the metal vessel *a* isolated from the ground, will charge it and the cylindrical electrode *B* electrically connected to it (Fig. 3). Then the next drop falling from the capillary *b*' will be charged by the negative charge induced from the electrode *B*, and this charge will be transferred to the vessel *b* and the electrode *A*. The next drops from the capillary *a*' will intensify their positive charge and the ones from the capillary *b*' their negative charge.

Thus, between the vessels *a* and *b* or the electrodes *A* and *B*, there appears a potential difference, which may be directly measured by an electrostatic kilovoltmeter, and in this case it will in fact be the KG emf. If the cylinders *A* and *B* are closed with a high-ohmic resistor, being a load resistance, current will flow in it.

The system of the vessels and electrodes (*a*, *B*) and (*b*, *A*) is a condenser, and the charge accumulated by it will be determined by the formula

$$Q = C\varepsilon, \quad (10)$$

where C is the electrical capacitance and ε is the KG emf.

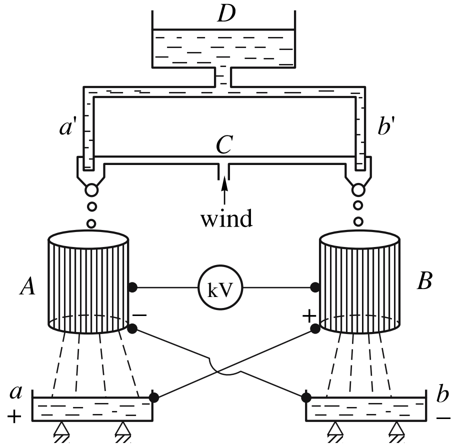

Fig. 4. Combined EGD generator.

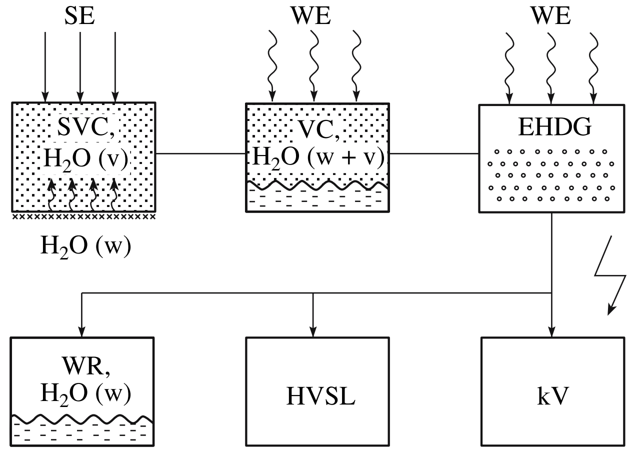

Fig. 5. Block diagram of wind energy complex with electrohydrodynamic generator. SVC is the solar vapor collector; VC is the vapor condenser; EHDG is the electrohydrodynamic generator; WR is the water reservoir; HVSL is the high-voltage supply line; SE is the solar energy; WE is the wind energy; ↓↓ is the solar radiation; ⇃ is wind; ↿ is vapor.

Hence, the condenser charging current is equal to

$$I = \frac{dQ}{dt} = C\frac{d\varepsilon}{dt}. \qquad (11)$$

Let us note that, as the dimensions of drops increase, their merging occurs and the jet mode of KG operation takes place when the generated potential difference increases significantly. The simplest KG with dimensions of the vessels *a* and *b* and the cylinders *A* and *B* of about 10 × 10 cm can give an emf ε up to 10–15 kV for several minutes. In the jet mode, charging is realized in a matter of seconds.

A combined EGD generator is more effective. In it, drops from the capillaries *a*' and *b*' are additionally blown off by airflow by virtue of a special construction in the form of the pipe *C* put on the droppers *a*' and *b*' according to Fig. 4.

We do not dwell on details of the operation of the Kelvin generator in thunderclouds. It is probable that moist air jets in the combined variant in Fig. 4 will give some explanations.

Connection of the foregoing components of the system with the EHD generator is realized directly through the condenser flow into the vessel *D* feeding the EHD generator; a schematic diagram of the whole energy system is shown in Fig. 5. The presence of the Kelvin generator instead of an electrogasdynamic one is one more difference of the initial variant of the system from the considered laboratory one.

The system operates according to the following scheme. Owing to solar heating, water evaporates from the soil, forming moist air in the collector. Under favorable conditions, moist air penetration from the outside of the SVC is admissible. The moist air owing to natural convection flows into the vapor condenser, from where it goes, in the form of a condensate, to the EHD generator or KG, or to a generator of combined type. If necessary, the condensate may flow into the water reservoir (WR) through the faucet K. From the EHDG, the process water goes to the WR, from where in organization of a cycle it can again flow to the collector through the drainpipes. The generated emf after relevant transformations is fed to the high-voltage supply line for consumers of electric energy.

In the laminar mode at $h = 0.07$ m and $\alpha = 27°$, on average $G_C \sim 10^{-4}$ kg/s and emf of ~15 kV at $I \sim 1$ μA were obtained. In natural conditions, these effects are shown to be tens of times stronger.

CONCLUSIONS

The possibilities of obtaining of water and electric energy from the atmosphere and soil are considered, and ways to realize them are discussed.

Physical considerations and formulas are given, according to which an experimental installation simulating natural atmospheric processes of moisture circulation and separation of electric charges is designed.

The basic possibility of physical modeling of the aforementioned processes under laboratory conditions and their practical application is shown.

Along the complicated track of studying atmospheric phenomena, including electrical phenomena, for both scientific and applied purposes, only the first steps have been done, which indicate that reserves exist for improvement of the solar energy electrohydrodynamic system.

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