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DESTRUCTION OF BERNARD CELLS UNDER LOCAL IRREGULARITIES OF THERMAL EQUILIBRIUM AND THEIR FORMING OVER THE BERNARD CELLS

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Results of the experiments on destruction of Bernard cells are described. Destruction of BC was conducted by two ways: micro-drop of the cooled vacuum oil, dropped on the surface of the formed Bernard cells and local change of temperature of the upper border of the layer with heated copper wire. It was offered to study the destruction of convective Bernard cells on the Sun (super-granules) as the result of quick heating of their lower border. Mathematical description of the destruction mechanism is presented. Method of calculation of volume expansion of the solar matter is presented. Value of coefficient of volume expansion was obtained which allowed decreasing the Rayleigh number of the super-granule to the value of free cell. It was shown that increase on the order of the temperature of lower boundary of the super-granule, results in the increase of Rayleigh number and as a sequence in acceleration of the solar matter. Acceleration time of the solar matter to the second orbital velocity was estimated. It constitutes 3·10 s, and time of solar matter outburst (eruptive flare) is about $2.23\cdot10^3$ s. Distance of solar matter outburst is about $7\cdot10^8$ m and comparable with the Sun radius. Experimental results on forming the air Bernard cells over the oil Bernard cells is described and numerically analyzed. Correspondence of sizes of air Bernard cells to ones of oil Bernard cells is explained.
KEYWORDS: elementary convective cell, convective processes, transfer of heat, temperature gradient, velocity of mass transfer

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ РАЗРУШЕНИЯ ЯЧЕЕК БЕНАРА ПРИ ЛОКАЛЬНЫХ НАРУШЕНИЯХ ТЕПЛОВОГО РАВНОВЕСИЯ

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В работе описаны результаты экспериментального исследования разрушения ячеек Бенара. Разрушения ячеек Бенара проводились двумя способами: добавлением микрокапли более холодного вакуумного масла на поверхность ячеек и локальное изменение температуры верхней границы слоя разогретым медным щупом. Было предложено изучение разрушение конвективных ячеек Бенара на Солнце (супергранул) в результате быстрого нагрева их нижней границы. Представлены математическое описание механизма разрушения и метод расчета объемного расширения солнечного вещества. Значение коэффициента объемного расширения получено, что позволило уменьшить число Рэлея супергранулы до значения свободной ячейки. Было показано, что увеличение порядка температуры нижней границы супергранулы, приводит к увеличению числа Рэлея и, как следствие, к ускорению солнечного вещества. Было оценено время ускорения солнечного вещества, оно составляет 3·10 с, а время выброса солнечного вещества (эруптивной вспышки) составляет около $2.23\cdot10^3$ с. Размер вспышки солнечной материи около $7\cdot10^8$ м и он сопоставим с радиусом Солнца. Экспериментальные результаты формирования воздушных ячеек Бенара над масляными ячейками Бенара описаны и численно проанализированы. Объяснено соответствие размеров ячеек Бенара в воздухе и масле.
КЛЮЧЕВЫЕ СЛОВА: элементарная конвективная ячейка, конвективные процессы, перенос тепла, температурный градиент, скорость массопереноса

ЕКСПЕРІМЕНТАЛЬНЕ ДОСЛІДЖЕННЯ РУЙНУВАННЯ КОМІРОК БЕНАРА ПРИ ЛОКАЛЬНИХ ПОРУШЕННЯХ ТЕПЛОВОЇ РІВНОВАГИ

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У роботі наведені результати експериментального дослідження руйнування комірок Бенара. Руйнування комірок Бенара виконувалось двома методами: додаванням мікрокраплі найбільш холодної вакуумної оливи на поверхню комірок та

локальна зміна температури верхньої границі слою розігрітим мідним щупом. Було запропоновано вивчити руйнування конвективних комірок Бенара на Сонці (супергранул) шляхом швидкого нагріву їх нижньої границі. Наведено математичний опис механізму руйнування та методу розрахунку об'ємного розширення сонячної речовини. Отримано значення коефіцієнту об'ємного розширення, що дозволило зменшити число Релея супергранули до значення вільної комірки. Було показано, що збільшення порядку температури нижньої границі супергранули призводить до збільшення числа Релея та, як результат, до прискорення сонячної речовини. Оцінено час прискорення сонячної речовини, він складає $3{\cdot}10$ с, а час виносу сонячної речовини (еруптивного спалаху) складає майже $2.23{\cdot}10^3$ с. Розмір спалаху сонячної матерії $7{\cdot}10^8$ м та він порівняний із радіусом Сонця. Експериментальні результати формування комірок Бенара у повітрі та в оливі описані та чисельно проаналізовані. Пояснена відповідність розмірів комірок Бенара у повітрі та маслі.
КЛЮЧОВІ СЛОВА: елементарна конвективна комірка, конвективні процеси, перенесення тепла, температурний градієнт, швидкість масопереносу

CONCERNING THE FORMATION AND DESTRUCTION OF CONVECTIVE CELLS. TASK DEFINITION

Phenomenon of self-organization under heat convection in the layer of viscous fluid, heated from below, that was discovered by Claude Bernard (1874–1939), French physicist, has been of interest for researches for more than a century [1]. The reason of the interest lies in the striking universality of the discovered phenomenon. It is used in different technological processes, very often can be observed in every day life. There are also hypotheses that explain some phenomena on the Sun and in Earth atmosphere, with the theory of Bernard cells. In all such cases, researches, as a rule, pay attention on the formed spatially periodic structure of surfaces of different configuration: from the strips to densely pave with polygons (not necessary accurate), reflecting its convective flow between the layer borders. However till present time, the problem of existence of convective cells (basic cells) from which the Bernard cell systems are formed, remained without attention.

As the experiments show [2], spatially periodic structures do not appear instantly, but there is a time interval, during which the number of separated cylindrical convective cells is growing. Finally, they fill the whole volume of liquid, creating for example the Bernard cells. Papers [2, 3] offer description of elementary convective cell, from a large number of which the spatially periodic stable in time structures appear.

Due to forming of such spatially periodic structures, the appropriate interest appears in research of their influence on the media with restrict them from above. This media can be either liquid or gaseous. Experiments on simulation of forming the convective cells in the layer of silicone oil with free boundaries, placed over the mercury layer and limited from above with helium layer, is mentioned in [4]. These experiments do not mention forming of convective cells in helium over the cells in oil, although observations of lower boundary of the clouds [5], and also boundaries oil-air [2] indicate on formation of Bernard cells in the boundary mediums. That is why research of origination of convective cells formed with Bernard cells is relevant for determination of conditions and physical principals of their origination.

Together with phenomenon of forming the time stable spatially periodic structures, processes of their destruction remain unstudied. Example of such destruction is probably the outburst of prominences from the Sun convective area. That is why determination of conditions and mechanisms of destruction of convective cells is also the actual problem.

Questions concerning the formation and destruction of convective structures demand experimental research and theoretical analyses for explanation of nature of such phenomena.

Purpose of this paper is the experimental research of destruction of convective cells for different mechanisms of destruction of thermal equilibrium including the processes of destruction of convective cells on the Sun and also research of processes of forming the Bernard cells by other Bernard cells.

DESCRIPTION OF EXPERIMENTS ON FORMING THE CONVECTIVE CELLS IN CYLINDRICAL TANKS WITH OIL

Experiments on forming the convective cells were carried out with usage of vacuum oil BM-5 (2 ml), in which small quantity of aluminum powder (0.056 g) was added for visualization of oil movement.

Conditions of carrying out experiments were as follows:

Oil with layer thickness about 1 mm was poured into cylindrical tank with radius 26 mm and height 2.5 mm. Heating of the tank was carried out from below with electrical furnace. Oil temperature on the tank bottom could raise to the level of 220 °C. Kinematic viscosity of the vacuum oil under mentioned temperatures was estimated with value 10 mm^2/s [6].

Experiments were carried out in two stages.

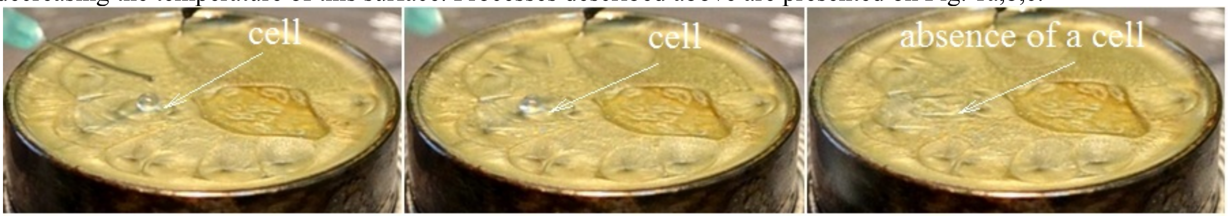
At the first stage conditions of origin of long-lived convective cells in the form of densely packed polygons including hexagons were determined. Within the experiments it was shown that when the temperature of the tank bottom reaches 120 ± 1 % °C the convective cells appeared with diameter 3.2 mm [2, 3].

At the second stage on the upper boundary of oil, we created conditions, which resulted in quick (in comparison with the time of convective cells existence) change of its temperature. These conditions had been created by two ways. The first one consisted in dropping the cold micro-drops on the oil surface. The second one consisted in broughting the copper wire, which was heated to the temperature of the tank bottom, to the center of one of the convective cells.

DESTRUCTION OF CONVECTIVE CELLS DUE TO THE COOLING OF THE UPPER BOUNDARY, CAUSED BY ADDING THE MICRO-DROP OF THE COLDER OIL

Micro-drop of vacuum oil without adding the aluminum powder with temperature 17 °C was dropped on the upper boundary of convective cells from 1 ml syringe with needle 0.4×13. Due to great difference of temperatures of the upper oil layer and the micro-drop, Leidenfrost effect was observed [7]: when the micro-drop liquid in contact with much more hot oil creates the isolation layer of vapor, which prevents the micro-drop liquid from quick boiling-off.

As a result of this, the mirco-drop moves for some time over the surface of oil on the vapor blanket, created on its lower boundary. Then, the micro-drop temperature increases, micro-drop is destroyed and spreads over the oil surface, thus decreasing the temperature of this surface. Processes described above are presented on Fig. 1a,b,c.



a) b) c)

Fig. 1. Destruction of convective cells in vacuum oil by micro-drop of the cooled vacuum oil.

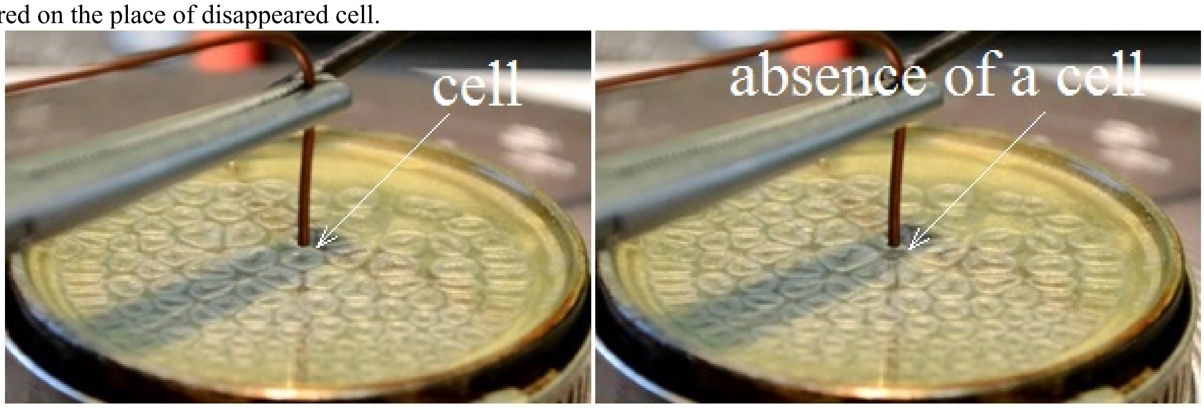
Fig. 1a shows initial position of vacuum-oil micro-drop after its dropping on the oil surface. It is seen on the figure, that at first the micro-drop is placed to the right from the center of the convective cell. Then due to Leidenfrost effect it moves a little to the right (Fig. 1b) from the cell center. After spreading of micro-drop of colder oil over the cell surface (Fig. 1c) its destruction is observed. According to our estimates destruction of cell is stipulated with the decrease of temperature of the upper boundary of the convective cell: the decrease of temperature increases Rayleigh number and transfers the eigenvalue λ of the boundary problem from the zero value, corresponding to stationary condition [3], to the area of negative numbers under which the equilibrium is distorted and convective cells are destroying.

It should be noted that burst of micro-drop of the hot oil on convective cell does not result in Leidenfrost effect and its destruction.

Thus, it is experimentally shown that decrease of temperature of the upper boundary of convective cell, which is caused by dropping the cold oil drop on its surface, results in destruction of convective cell.

DESTRUCTION OF CONVECTIVE CELLS UNDER CONTACTLESS HEATING OF THE UPPER OIL BOUNDARY WITH COPPER WIRE

The upper boundary of the selected convective cell was contactless influenced with thin heated cooper wire with diameter 1 mm, not destroying convective flux in the cell. Start and completion of the process of wire influence on the cell is presented on Fig. 2 a) and b) correspondingly. From the presented pictures it follows that at the beginning of the process the cells was stable and had accurately outlined boundaries. After approaching to the center of convective cell with the heated copper wire with diameter 1 mm destruction of cell took place within 1–2 s, which lied in disappearance of its border and destruction of convective flux. Then, during the some period of time, convective cell of the same type appeared on the place of disappeared cell.



a) b)

Fig. 2. Destruction of convective cells in vacuum oil by copper wire.

Fig. 2 a) shows convective cell at a moment after approaching the heated copper wire. Fig 2 b) corresponds to the moment with 3–5 s after approaching the wire. As we can see from Fig. 2b), the convective cell destructed due to influence with the heated copper wire.

Based on the experiment carried out it can be concluded, that decrease of temperature of the upper boundary of the convective cell in vacuum oil as a result of influence with heated copper wire results in cell destruction.

DESTRUCTION OF CONVECTIVE CELLS ON THE SUN AS A RESULT OF QUICK HEATING OF THEIR LOWER BOUNDARY

It is known that in convective area of the Sun, with length 2×10^5 km, convective cells of different sizes are observed. Due to flares on the Sun, special attention, is paid to super-granules, placed in the lower layers of convective zone with characteristic sizes: diameter of $(2-4)\times10^4$ km, thickness of $(3-8)\times10^3$ km [7, 8]. Life-time of the super-granules constitutes the value about $\tau_v \approx 20-36$ hours. Movement of the solar matter corresponds to the movement in *l* cells [11], that is in the center of the cell matter moves from the Sun center.

Due to this it is interesting to study the flares on the Sun[12; 13], as the studied above result of quick change of temperature of the lower boundary of convective cells (supergranules). Fig. 3 shows pictures of separate moments of powerful solar flare, obtained by step-by-step image scanning of video of the solar flare, registered by American space agency (NASA) 01.09.2014 [13].

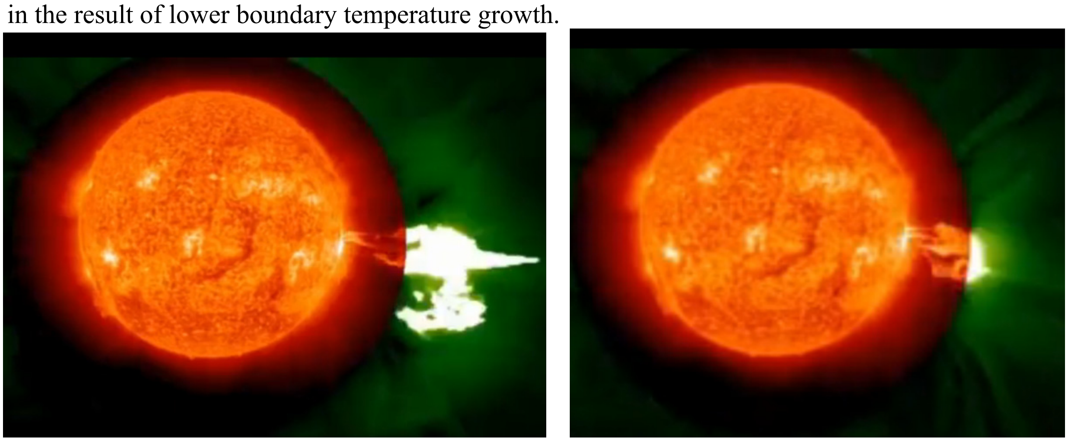
According to [13], statistic analyses of data on the soft X-rays of the Sun determines three types of flares: quick flares with duration not more than 30 min; typical two-ribbon flares with duration to 1-2 hours; rare long duration events (LDE). LDE consist of flares with complicated space-time structure. At this one or several flare peaks can form post-eruptive flares in the form of arcs. Raise of the arc system, as a rule, is finished on the height from 3×10^4 to 10^5 km, but in rare cases it parts goes into interplanetary space.

Fig. 3 shows that flare is finished on the heights about the Sun diameter and belong to the type when arc systems go into interplanetary space. Presented fragments of the flare confirm, that, evidently, it is formed by several connected super-granules. Conclusion on participation of several super-granules in the flare is made from the following visual facts:

1. Area of several active spots on the Sun disk, which does not result in ejection of matter, are formed from several supergranules;
2. Presence of ruled flash in the basis of solar flare confirm that each such line correspond to matter ejection from the center of super-granules participating in the flare.
3. Estimation of the diameter of the base of solar flare, carried out with use of Fig. 3 provides the value in the range from 6×10^4 to 12×10^4 km, that is several time greater than diameter of a super-granule.

The video of the solar flare dated 01.09.2014 [13] shows that tail part of the ejected matter returns on the Sun surface under gravity force and head part goes into interplanetary space. Most likely this can be explained by the fact that head part of the solar flare in the process of development of instability in the super-granule obtains second orbital velocity (617.7 km/s) and can overcome the Sun gravity.

Below we give the estimations confirming the possibility of development of the instability in the separate supergranule in the result of lower boundary temperature growth.



a) b)

Fig. 3. Separate moments of the powerful solar flare registered by NASA 01.09.2014
(a) the head part of powerful solar flare goes to interplanetary space, (b) the tail part of ejected matter flashes are coming back to the surface of the Sun by gravity.

Let's describe velocity, lifetime and distance of solar flare outburst based on the analyses of processes in the composing super-granules. For this present distribution of velocities in the separate super-granule with expression describing distribution of velocities in the elementary convective cell with free boundary conditions for mode number n = 1 [2, 3]:

$$\mathrm{v}_z\left(r,z,t\right)=A\sin\left(\pi z\right)J_0\left(k_{r,1}r\right)\exp\left(-\lambda_{1,1}^{-}\left(Ra\right)t\right), \qquad (1)$$

$$\mathrm{v}_r\left(r,z,t\right)=-A\pi k_{r,1}^{-1}\cos\left(\pi z\right)J_1\left(k_{r,1}r\right)\exp\left(-\lambda_{1,1}^{-}\left(Ra\right)t\right), \qquad (2)$$

where $\lambda_{1,1}^{-}(Ra) = \frac{P+1}{2P}\left(\pi^2 + k_{r,1}^2\right) - \left(\left(\frac{P-1}{2P}\right)^2\left(\pi^2 + k_{r,1}^2\right)^2 + \frac{Ra \cdot k_{r,1}^2}{P\left(\pi^2 + k_{r,1}^2\right)}\right)^{\frac{1}{2}}$ – eigenvalues, characterizing the decrease ($\lambda_{n,1}^{-} > 0$), increase ($\lambda_{n,1}^{-} < 0$) or steady state ($\lambda_{n,1}^{-} = 0$) of the perturbed velocities, $Ra = g_{Sun}\beta h^3\Theta/(\nu\chi)$ – Rayleigh number, h – cell thickness, g_{Sun} – acceleration of gravity on the Sun, $P = \nu/\chi$ – Prandtl number, ν и χ – coefficients of kinematic viscosity and thermal diffusivity correspondingly, β – coefficient of volume temperature expansion of the matter, $J_l(x)$ – Bessel functions of the first kind of the l-order; $k_{r,1} = \sigma_{1,1}R_c^{-1}$ – radial wave number, characterizing dependence of perturbations from the transverse dimensionless coordinate r, z – vertical dimensionless coordinate (origin of coordinates is placed at the center of bottom face of super-granule), $\sigma_{1,1}$ – 1st zero of the Bessel function of the first type of the first order ($J_1(\sigma_{1,i}) = 0$), R_c - dimensionless radius of the convective cell.

Quiet phase of the Sun. In steady state $\lambda_{1,1}^{-} = 0$. According to [10, 17], in steady state, the Rayleigh number for super-granule is equal to $R_S = 2\cdot10^7 \div 2\cdot10^{11}$, which significantly exceeds the minimal critical Rayleigh number for free convection– [15, 18] $R_m = \frac{27}{4}\pi^4 \approx 657{,}511$. That is why it is necessary to remove this disagreement in determination of R_c number. For this we will calculate the Rayleigh number using the following characteristic parameters for the Sun: $P \approx 0.7...1.0$ [10, 17]; $\nu \le 2\cdot10^9$ m^2/s [19]; $h = 10^7$ m [10]; $g_{Sun} = 274$ m/s^2; $\Theta = T_2 - T_1 \approx 10^6$. It is needed to mention that value of kinematic turbulent viscosity $\nu \le 2\cdot10^9$ m^2/s is confirmed with simple calculation: $\nu = h^2/\tau_\nu = 10^{14}\,м^2/(0.72..1.3)10^5 s = (0.76..1.4)\cdot10^9$ m^2/s.

During the calculations we suppose that in lower layers of convective zone under, where super-granules are placed, the temperature is changed according to the linear law $T(z) = T_2 - (T_2 - T_1)\frac{z}{h}$ within the range from $T_2 \approx 2.2\cdot10^6$ K to $T_1 \approx 1.34\cdot10^6$ K [20 - 22]).

In order to calculate the Rayleigh number R_S it is necessary to determine the value of coefficient of volume temperature expansion β of the solar matter.

When calculating β , we will be basing on the fact that the solar matter in convective zone constitutes mix of gases (hydrogen 68% and helium 30%[21]) in the ionization state, i.e. it exists in the form of plasma. In this case we will select the plasma volume as the widening volume, limited with Debye radius [23]: $V = \frac{4\pi}{3}r_D^3$, where $r_D = \sqrt{\frac{kT(z)}{4\pi e^2 n(z)}}$, $n(z)$ - density of ionized solar matter, k - Boltzmann constant, e - electron charge.

In this case the following expression is true for coefficient of volume temperature expansion:

$$\beta(z) = \frac{3}{r_D}\frac{dr_D}{dT} = \frac{3}{2T(z)}\left(1 + \frac{m_S g^*}{k}\left(\left(\frac{dT(z)}{dz}\right)^{-1} - \frac{z}{T(z)}\right)\right) = \frac{3}{2T(z)}\left(1 + \frac{m_S g^*}{k}\frac{T_2 h}{\Theta T(z)}\right), \quad (3)$$

where $m_S = 0.68m_H + 0.3\cdot m_{He} = 0.68m_p + 0.3\cdot4\cdot m_p = 1.88m_p$ - average mass of solar matter ion, m_p - proton mass. Expression (3) is obtained with use of barometric height formula [24] for solar matter.

In order to determine the Rayleigh number we will use average value of as the coefficient of volume temperature expansion coefficient $\beta = \bar{\beta}(z) = h^{-1}\int_0^h \beta(x)dx$, and select the value for the Prandtl number $P \approx 0.75$. Under selected above values of parameters the coefficient of volume expansion is equal $\beta = 4.179\cdot10^{-9}\frac{1}{K}$.

Finally obtain value $R_S = \frac{g^*\beta h^3\Theta}{\nu\chi} = \frac{274\frac{m}{s^2}\cdot4.179\cdot10^{-9}\frac{1}{K}\cdot10^{21}m^3\cdot7.9\cdot10^5K}{10^9\frac{m^2}{s}\cdot1.34\cdot10^9\frac{m^2}{s}} = 675.08$, which quantitatively corresponds to the critical Rayleigh number R_m for free convection.

Thus, parameters of the super-granule in the quiet Sun phase (in steady state), when the equality $\lambda_{1,1}^{-}=0$ is completed, are explicitly described with expression: (1) - (3).

Active Sun phase. Quiet phase of the Sun can be interrupted, if the temperature of the lower boundary of the super-granule will increase within the time Δt, which is significantly lower of the characteristic lifetime of super-granule: $\Delta t << \tau_{\nu 1}, \tau_{\nu 2}$, where $\tau_{\nu 1}=(1.4\pm 0.6)\cdot 10^{5}$ s or $\tau_{\nu 2}=(1.56\pm 0.78)\cdot 10^{5}$ s [10]. Due to internal processes in the Sun, the temperature value of the lower boundary of the several super-granules can reach the value exceeding greatly T_2 [22]. Such change of the temperature increases the Rayleigh number Ra_S, which results in changing the eigenvalue $\lambda_{1,1}^{-}$ in expressions (1), (2) from zero to negative value, resulting in exponential growth of vertical velocity amplitude (1) with the course of time.

From expression (1), time of vertical speed growth can be estimated, if the following basic parameters are assigned:

- initial solar matter velocity in the center of super-granule 30 m/s [10];
- radial wave number corresponds to the critical value: $k_{r,1}=\pi/\sqrt{2}\approx 2.221$;
- final speed of solar matter outburst is about or exceeds the second orbital velocity 617.7 km/s;
- super-granule lifetime in active phase of the Sun is much less than one in quiet phase of the Sun: $t_{\nu 1,\nu 2}^{a}\approx 10^{-3}\cdot\tau_{\nu 1,\nu 1}$.

In the assumption, that the temperature of the lower boundary of the super-granule increases to the solar core temperature [22], the vertical speed (1) is exponentially grown in accordance with the law $\mathrm{v}_z(r,z,t)\propto\exp\left(\left|\lambda_{1,1}^{-}(15.5R_m)\right|t\right)$, i.e. solar matter on the cell axis is accelerated.

Estimate the characteristic parameters of the "solar accelerator" in the result of increase of Rayleigh number to the value corresponding the temperature of solar core. Calculations indicate that eigenvalue of the task in this case is $\lambda_{1,1}^{-}(15.5R_m)\approx -50.0$. Then solar matter acceleration time to, as a minimum, second orbital velocity V_2 is estimated with a value $T_1=\frac{\tau_{\nu 1}^{a}}{50}\ln\left(\frac{6.177\cdot 10^{5}}{30}\right)=(2.9\pm 1.3)\cdot 10$ s or $T_2=\frac{\tau_{\nu 2}^{a}}{50}\ln\left(\frac{6.177\cdot 10^{5}}{30}\right)=(3.1\pm 1.55)\cdot 10$ s. Further accept that average acceleration time for the active Sun phase is equal to: $\overline{T}=3\cdot 10$ s.

After the solar matter receives second orbital velocity 617.7 km/s, the distance of eruptive outburst constitutes $L_a\approx 7\cdot 10^{8}$ m, and outburst time is $T_a\approx 2.24\cdot 10^{3}$ s.

It should be noted that solutions (1), (2) and conclusion on the acceleration of solar matter are correct for small amplitudes of the perturbed velocity, when quadratic summands in the system of non-linear Navier–Stokes [18] equations can be neglected [18]. This demand provides limitation on the perturbed vertical velocity of the solar matter V_z (0,1,t):

$$\frac{\left|\lambda_{1,1}^{-}(15.5R_m)\right|}{\pi}\frac{10^{7}}{\overline{T}}=\frac{50\cdot 10^{7}}{\pi\cdot 3\cdot 10}=5.3\cdot 10^{6}\,\frac{\mathrm{m}}{\mathrm{s}}>>\left|\mathrm{v}_z(0,1,t)\right|\frac{\mathrm{m}}{\mathrm{s}},\qquad (4)$$

which can reach the value of the second orbital velocity V_2.

Thus, in this section it is offered to study destruction of convective cells on the Sun as a result of quick heating of their lower boundary of the super-granules. Method of determination of coefficient of volume expansion of solar matter is described. Its use of allowes to show, that Rayleigh number and corresponding to it wave number for super-granule of the quiet phase of the Sun corresponds to the critical Rayleigh numbers for the free cell. Increase, by order, of the super-granule temperature results in increase of Rayleigh number and in acceleration of the solar matter. It is shown that solar matter acceleration time, for example, to the second orbital velocity, constitutes in average $3\cdot 10$ s and the solar matter (eruptive flare) takes place within the time about $2.23\cdot 10^{3}$ s and stretches for the distance about $7\cdot 10^{8}$ m, which is comparable with the Sun radius.

FORMING OF AIR CONVECTIVE CELLS OVER THE CONVECTIVE CELLS IN VACUUM OIL

In order to form the convective cells, vacuum oil BM - 5 (2 ml) and small quantity of aluminum powder were used. The temperature of the lower boundary was kept at the level 120 ± 1 °C, and the one of upper boundary was less by 10 °C. After formation of convective cells in oil, the tank was covered with glass cap, filled with smoke for visualization of convective processes in air.

Fig. 4 shows that air convective cells are formed over the oil surface. Air convective cells have sizes repeating the ones of oil cells. Direction of the convection in air cells corresponds to convection in *g* cells[11], i.e. reverse to the direction of convection in oil.

Identity of geometrical sizes of convective cells in oil and in air is expalined by their similarity. Convective fluxes in oil and in air should be similar, when Rayleigh number and Prandtl number are the same [15, 18]. We will show that it is true.

Value of the Rayleigh number R is presented in explanation to the expressions (1), (2), where acceleration of gravity on Earth $g = 9.81$ m/s^2 should be substituted instead of g_{Sun}. The data from the Table should be used to calculate the Rayleigh numbers R for air and oil.

Fig. 4. Air convective cells over the convective cells in vacuum oil.

Table

Thermal-physic parameters of the environment [16].

Name of the parameters	Air	Oil
β, K^{-1}	2.68×10^{-3}	2.97×10^{-3}
ΔT, °C	20	20
L, m	2×10^{-3}	2×10^{-3}
ν, m^2/s	2.29×10^{-5}	1×10^{-5}
χ, m^2/s	2.216×10^{-7}	7.38×10^{-7}

Based on the data [15] find the relation of Rayleigh numbers (air-oil):

$$\frac{(R)_{oil}}{(R)_{air}} = \frac{\dfrac{9.81\times2.97\times10^{-3}\times20\times10^{-9}}{7.38\times10^{-7}\times10^{-5}}}{\dfrac{9.81\times2.68\times10^{-3}\times20\times8\times10^{-9}}{2.29\times10^{-7}\times2.216\times10^{-5}}} = \frac{623}{829} = 0.75\pm0.3 \tag{5}$$

Result of calculations according to (5) shows, that Rayleigh numbers for air and vacuum oil coincide within the limits of errors of their measurements.

Mirror symmetry of the spatial location and distribution of velocities in convective cells is expalained by phenomenon of catching of air particles by moving oil particles on their interface due to development of Kelvin-Helmholtz instability [25].

Thus, the calculations show that Rayleigh numbers for two environments get into the interval where they are equal. It goes from this that convective cells, formed in air and in oil are similar, i.e. are described by the same solutions.

CONCLUSIONS

Experiments on research of destruction of convective cells are presented in this paper. Destruction of convective cells was carried out by two methods. The first one consists in dropping the micrio-drop of the cooled vacuum oil on the surface of the formed convective cells. The micro-drop exists on the surface for a long time due to Leidenfrost effect. The second method consists in local change of temperature of the upper boundary of the layer with heated copper wire of a large diameter. Destruction of convective cells on the Sun, as a result of quick heating of their lower boundary, was studied as an example. Mathematical justification of such destruction was presented. Method of definition of solar matter coefficient of volume expansion was described. It provided a possibility to show that Rayleigh number for super-granule corresponds to critical Rayleigh number for the free cell. It is shown that greatly increase of the super-granule lower temperature results in increase of Rayleigh number and as a sequence in acceleration of the solar matter. At this acceleration time of the solar matter to second orbital velocity constitutes $3\cdot10$ s, and solar matter carrying-out (eruptive flare) takes place within the time about $2.23\cdot10^3$ s, and stretches for the distance about $7\cdot10^8$ m, which is comparable with the Sun radius.

Experimental result on forming the air convective cells over the convective cell from vacuum oil is described and analyzed. Explanation of correspondence of sizes of air convective cells and convective cells in oil is provided.

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