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Laboratory modeling of thermals generation in geophysical environments by means of fluid bubble boiling method

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Abstract

It is used method of fluid bubble boiling with purpose of laboratory modeling of thermo-chemical convection in different geophysical mediums [1]. Preliminary experiments were carrying out in the abovementioned work. Here was used more wide interval of solution densities. Thanks to suggested method of bubble boiling for laboratory investigation of thermo-chemical convection were defined more precisely before obtained results: differentiation of solutions; generation layers with boundaries containing high concentration of accumulated pollution; second kind discontinuity of temperature-time dependence in the point of infinitesimal air bubbles formation, after which the straight line character of it turns into like parabolic one before achievement the bubble boiling point.

1. Introduction

In this report, on the base of the experimental complex – Thermobarochamber of Mikheil Nodia Institute of Geophysics – for the first time it is obtained new results on modeling of thermals origin and following formation of cumulus clouds in the atmosphere and other geophysical fluids, convective motions giving rise mantle plumes, volcanoes, thermal waters etc. Investigation of these thermo-chemical convective motions, connected with extraordinary phenomena of nature (thunderstorms, hailstorms, volcanoes, relative motion of plates, earthquakes etc.), is one of the most actual scientific and socioeconomic problems. Difficulties of numerous experimental, numerical, and theoretical studies of these processes have led scientists to the necessity of carrying of corresponding laboratory experiments [1]. Here was used wide interval of solution density; thanks to suggested method of bubble boiling for laboratory investigation of thermo-chemical convection between existing layers were obtained intermediate layers with high concentration of accumulated pollution; discovery of second kind discontinuity of temperature-time dependence at the point $T_{bf}(t)$ of intensive infinitesimal air bubbles formation till the point $T_{bb}(t)$ of solution bubble boiling (note, that function $T(t)$ in interval $T_0(t)$ - $T_{bf}(t)$ is linear, and in $T_{bf}(t)$ - $T_{bb}(t)$ is parabolic). All authors unanimously declared that appeal to the laboratory experiment is only right way for successful solution of the difficulties connected with this problem [1-10].

2. Scheme of device and characteristics of thermodynamic system

There are provided and analyzed results of joint laboratory experiments by method of fluid bubbly boiling in modeling of the process of thermals formation in different geophysical environment, in particular, of cumulus clouds, differentiation of under-cloud /over-cloud ranges etc.

Below, Fig. 1 shows the scheme of device for modeling of vertical one-dimensional two-phase thermal motion.

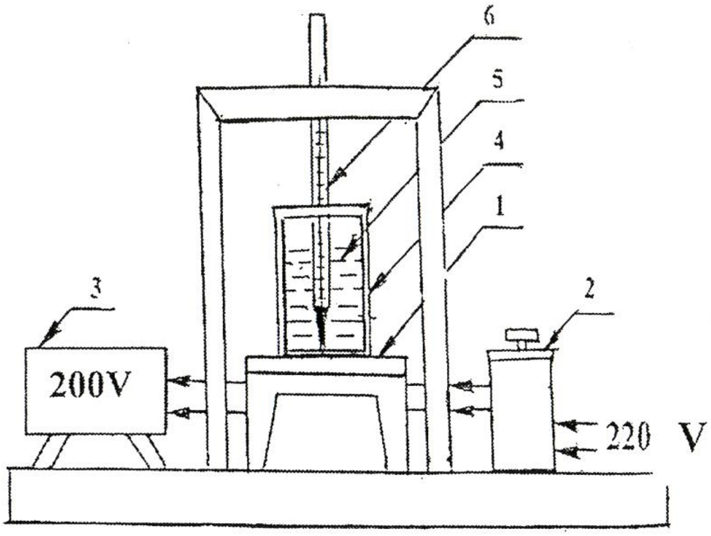


Fig. 1. Scheme of the experimental device: 1 – electrical heater; 2 – laboratory auto-connected transformer; 3 – voltmeter; 4 – chemical retort; 5 – glucose solution; 6 – thermometer.

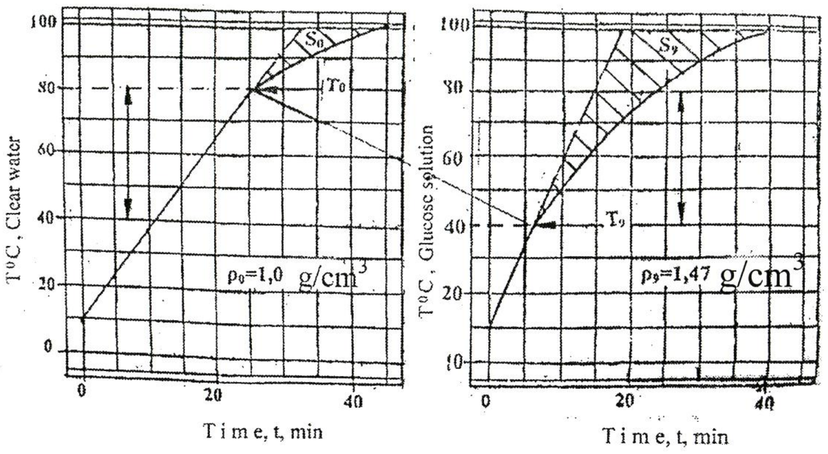
Fig. 1 shows the minimum of necessary instruments to conduct experiments with high accuracy and completeness of information about all parameters of the system. Although, this scheme is very simple, however, as proved during careful and repeated experiments, we establish some important phenomena accompanying boiling process (reflected partly in the figures and tables).

III. Bubble-boiling method: Preliminary experimental results

In chemical retort, firstly, clear water (at initial temperature 10^0C, density ρ_0 = 1.00 g/cm^3) was used as object of investigation, and then – series of glucose solution with following values of density: ρ_1 = 1.04 g/cm^3, ρ_2 = 1.08 g/cm^3, ρ_3 = 1.13 g/cm^3, ρ_4 = 1.18 g/cm^3, ρ_5 = 1.23 g/cm^3, ρ_6 = 1.29 g/cm^3, ρ_7 = 1.35 g/cm^3, ρ_8 = 1.41 g/cm^3, ρ_9 = 1.47 g/cm^3.

Fig. 2 shows graphical dependence of temperature water (in ^{0}C) on time (in min.). It is evident two stages in the processes of heating both clear water and considered glucose solutions. One can see as straight lines in case of clear water, ρ_0 = 1.00 g/cm^3, just at temperature T_{dc} = 80^0C (Fig. 2a), and glucose solution of maximal density, ρ_9 = 1.47 g/cm^3, at temperature T_{dc} = 40^0C (Frig. 2b), undergo discontinuity of second kind, respectively. Shaded sectors show the degree of curves deviation from linearity, respectively. These two points of discontinuity, T_{dc}, are joined by straight line in Figs. 2a, b.

Table 1 contents results of measurements of temperature changing with time beginning heating of clear water (ρ_0 = 1.0 g/cm^3) and glucose solution (ρ_9 = 1.47 g/cm^3) from T = 10^0 C to the point of boiling T = 100^0 C. Difference is evident: in intervals of temperature $\Delta T = (10 - 50)^0$ C (first five cases of measuring) time of clear water heating is twice more than in case of glucose



(a) **(b)**

Fig. 2. Temperature-time dependence of fluid heated below: (a) – clear water (ρ_0 = 1.0 g/cm^3); (b) – glucose solution (ρ_9 = 1.47 g/cm^3).

solution maximal density; then the values of these times approaches to each other, nevertheless, the difference between them remains and equals to Δt = 5 min at the boiling temperature T = 100^0 C. In the same relations are the quantity of clear water and the solution heat, respectively. Here also in the first five cases Q of the clear water twice more then Q of the glucose solution, these values approach to each other still the boiling point T = 100^0 C, where difference between them equals to ΔQ = 4500 cal.

Table 1. Dependence of temperature interval of clear water and glucose solution of maximal density on time and intensity of heating.

	Clear water, ρ_0 = 1.0 g/cm^3			Glucose solution, ρ_9 = 1.47 g/cm^3		
№ s	Temperature T^{0}C	Time t, min	Heat Q, cal	Temperature T^{0}C	Time t, min	Heat Q, cal
0	10	0	0	10	0	0
1	20	4	3600	20	2	1800
2	30	8	7200	30	4	3600
3	40	13	11700	40	6	5400
4	50	17	15300	50	9	8100
5	60	22	19800	60	14	12600
6	70	26	23400	70	18	16200
7	80	31	27900	80	24	21600
8	90	37	33300	90	30	27000
9	100	45	40500	100	40	36000

All 10 points of above mentioned solution densities represent in Fig. 3. It is well seen smooth passage of the curve from point to point before the point s = 6 (i.e. ρ_6 = 1.29 g/cm^3), after which the temperatures of discontinuity (T_{dc}), for last four values of density of sugar solution (ρ_6 = 1.29 g/cm^3,

ρ_7 = 1.35 g/cm^3, ρ_8 = 1.41 g/cm^3, and ρ_9 = 1.47 g/cm^3), coincide ($T_{dc,6} = T_{dc,7} = T_{dc,8} = T_{dc,9}$) and equal to 40^0 C.

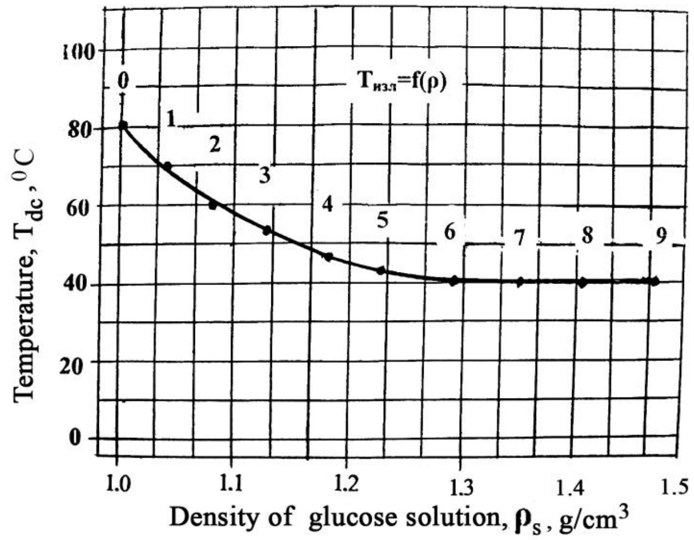


Fig. 3. Temperature of discontinuity, T_{dc}, dependence on the density of clear water (ρ_0 = 1.0 g/cm^3) and densities of glucose solution (ρ_s, g/cm^3), (s = 1, 2, …, 9).

Fig. 4 and 5 shows the maximal difference between clear water and glucose solution of density ρ_9 = 1.47 g/cm^3.

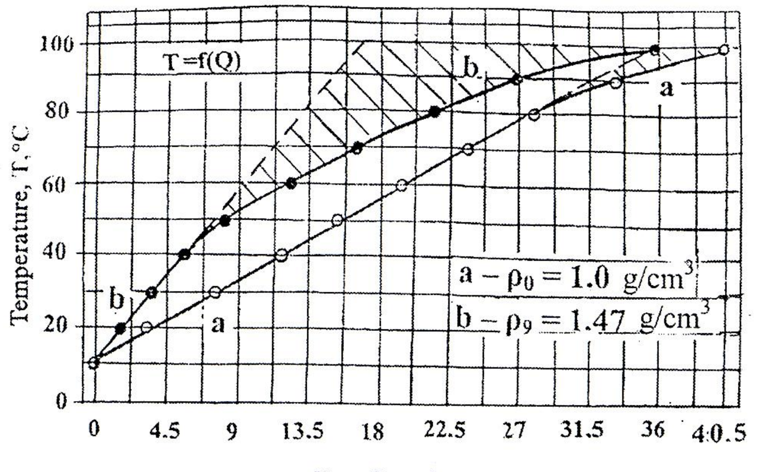


Fig. 4. Temperature dependence of glucose solution heated below upon heating flux: (a)– clear water (ρ_0 = 1.0 g/cm^3); (b) – glucose solution (ρ_9 = 1.47 g/cm^3); (circles denote temperatures of discontinuity, $T_{dc}(t)$, corresponding to ρ_s, (s = 0, 1, 2, . . . , 9).

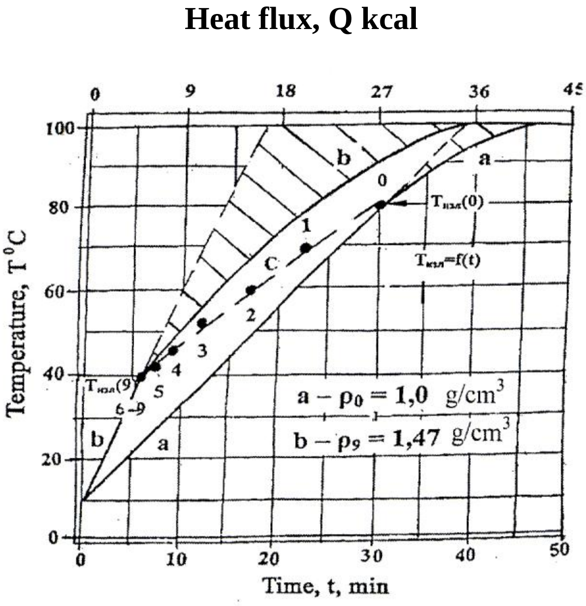


Fig. 5. Temperature-time and heat flux-time dependence at fixed density of solution ρ_S (solid lines): (a) corresponds to clear water (s = 0, ρ_0 = 1.0 g/cm^3); (b) – to maximal density of glucose solution (s = 9, ρ_9 = 1.47 g/cm^3); (c) -T_{dc} (t) temperature of discontinuity corresponds, including clear water, to all values of density, ρ_S, (s = 0, 1, 2, . . . , 9), (dashed line).

Table 2. Dependence of clear water and glucose solutions entropy for 10^{0}C of temperature intervals on the density, ρ_S, of solution.

№ s	Density of solution, ρ_S, g / cm^3	Intervals of temperature, ΔT, ^{0}C					
		40-50	50-60	60-70	70-80	80-90	90-100
		Entropy, ΔS = ΔQ / T, cal / ^{0}C					
0	1.0					630	900
1	1.04				450	585	810
2	1.08			495	495	630	720
3	1.13			405	504	675	900
4	1.18		360	405	450	580	900
5	1.23		360	405	450	630	900
6	1.29	360	360	360	450	640	900
7	1.35	270	270	370	450	675	900
8	1.41	360	360	60	450	630	900
9	1.47	315	360	405	450	540	900

Below, by construction of Fig. 6 we wish to sum up results of our preliminary experiments on modeling of convection process which are in any liquid and gaseous geophysical environment or, in short, to describe whole process of heating and boiling glucose solution from beginning to the end. As concerns Table 3, it adds the data of Tables 1- 2 and Figs. 2-5, too.

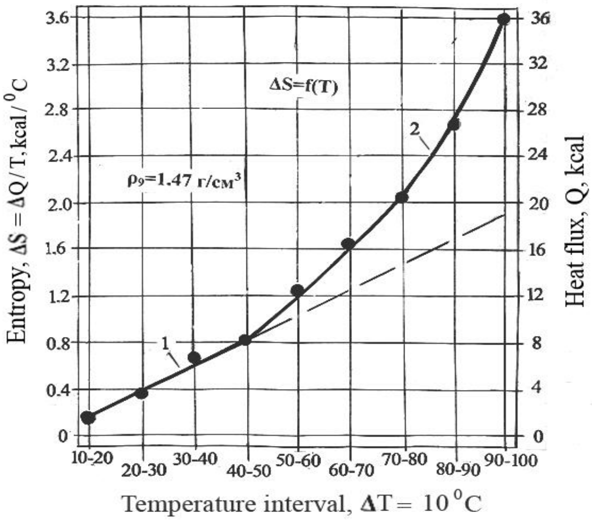


Fig. 6. Entropy-temperature graphic dependence of glucose solution with density $\rho_9 = 1.47$ g/cm^3 using $\Delta T = 10^0$C intervals. Dashed line shows deviation of the solid line from linearity after point (40-50, 0.8).

The graphic dependence between the entropy increase ($\Delta S = \Delta Q/T$) and selected from ((10-100) ^{0}C) range 10^0C-step temperature intervals is represented in Fig. 6.

Temperature intervals (10-20, …) along the abscissa axis correspond to the respective temperatures of discontinuity. Detailed analysis of the entropy growth dependence on temperature of the glucose solution with density $\rho_9 = 1.47$ g/cm^3 shows that the value of entropy is indicator of system's state at transfer from one condition to the following one. At that moment, corresponding to the temperature of discontinuity, T_{dc} , the system (solution) transfer from state of great number of least vapour bubbles, slowly ascending thermal-plumes (first stage – bubbly flow) to the state of bubble slug.

Table 3. Main heat characteristics of different density glucose solutions from the beginning of heating the glucose solutions to the bubbly boiling process.

№ sol	Temperature intervals, T, ^{0}C	Entropy, $\Delta S = \Delta Q / T$, kcal / ^{0}C	Correlation $\Delta S_{100}{}^0C / \Delta S_{20}{}^0C$	Correlation $\Delta S_{100}{}^0C / \Delta S_{40}{}^0C$
1	10-20	180	3600 / 180 =	
2	20-30	360	= 20	
3	30-40	540		3600 / 540 =
4	40-50	810		= 6.6
5	50-60	1260		
6	60-70	1620		
7	70-80	2115		
8	80-90	2700		
9	90-100	3600		

It is interesting to compare our results (Figs. 2-6 and Tables.) with Nukiyama's Fig. 7.

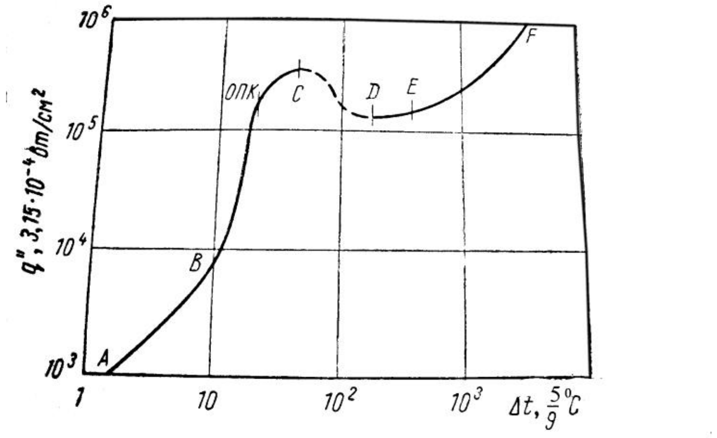


Fig. 7. Boiling of water at 100^{0}C on the electrically heated platinum wire. Maximal flux for bubbly boiling (Nukiyama (1934), see [3]).

Comparison and analysis of our results on clear water and nine cases of sugar solution densities (Figs. 2-6, Tables), and Nukiyama's (1934) ones (Fig.7) on only clear water, showed their accordance with each other. In both cases heat fluxes was the same order (~ 2.0 W/cm^2, in our case, against 3.14 W/cm^2 of Nukiyama (1934)); moreover, the angles of deviation from linearity between dashed and solid lines in Fig. 6 and between AB and BC parts of the curve of Fig. 7 are nearly the same.

Fig. 8. Photographs of convective clouds with individual towers (Tbilisi, Georgia).– by A. G.

Fig. 8 shows typical cumulus clouds over outskirts of Tbilisi: it is well seen as cloud towers visualize the atmospheric thermals – individual and groups of cloud towers; heat flux over the hilly partly wooded territory (and in the winter sea) is about ~ 100 W/m^2 [7-9]; our modeling heat flux equals to 2 W/cm^2; Parameters of convective clouds are following: vertical middle velocities of— about 3-5 m/sec, near the base of cloud dimensions.

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Лабораторное моделирование процесса термикообразования в атмосфере методом пузырькового кипения жидкости

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Резюме

В данной работе на базе комплекса Термобарокамеры Института геофизики впервые, методом пузырькового кипения жидкости, ставятся и анализируются совместные эксперименты по моделированию термохимической конвекции, процесса образования термиков в различных геофизических средах, в частности, образования кучевых облаков, расслоения подоблачной и облачной сред и пр. Исследование конвективных движений, связанных с экстраординарными явлениями природы (штормы, вулканы, движение тектонических плит, землетрясения и др.) является одним из самых актуальных научных и социоэкономических проблем. Трудности численных экспериментов, численных и теоретических исследований этих процессов привели учёных мира к признанию необходимости проведения соответствующих лабораторных экспериментов. Последние имеют не только прикладное, но и самостоятельное значение. Предложенным методом пузырькового кипения для лабораторного моделирования термохимической конвекции был получен ряд новых результатов (see [1]). Для широкого диапазона плотностей растворов в ходе кривых зависимости температуры T(t) и энтропии S(T) обнаружены точки разрыва непрерывности второго рода (в диапазоне $(40\text{-}80)^0$ C), после которой кривые отклоняются от начального линейного хода, изгибаются и параболически приближаются к точке кипения 100^0 C.

ატმოსფერული თერმიკების წარმოშობის ლაბორატორიული მოდელირება სითხის ბუშტისებრი დუღილის მეთოდის მეშვეობით

ა. გველესიანი, ნ. ჭიაბრიშვილი

რეზიუმე

ბუნების ექსტრაორდინარული მოვლენების სრული სახით აღწერა რიცხვითი ექსპერიმენტების, რიცხვითი და თეორიული მეთოდების გამოყენებით ჯერ–ჯერობით გადაულახავ ამოცანადაა გამოცხადებული მსოფლიო მეცნიერების მიერ, რამაც აიძულა ერთხმად ეღიარებინათ ლაბორატორიული ექსპერიმენტების /ანუ ლაბორატორიული მოდელირების აუცილებლობა.

შემოთავაზებული ბუშტისებრი დუღილის მეთოდით კონვექციური მოძრაობების სხვადასხვა გეოფიზიკურ თხევად არეში, კერძოდ, გროვა ღრუბლების წარმოშობის მოდელირების მიზნით ჩატარებულია წინასწარი ლაბორატორიული ცდები. ცდები ტარდებოდა მრავალფენოვან ხსნარებზე [1]: წყალი–შაქრის ხსნარი–ზეთი–წყლის ორთქლი. შეისწავლებოდა ერთიდაიმავე მოცულობის მქონე წყლის შაქრის ხსნარების გათბობის დუღილამდე მიყვანის სრული პროცესი. პროცესის დროს მდუღარე სუფთა წყლის და ხსნარების სიმკვრივის ფართო დიაპაზონის მნიშვნელობებისათვის თერმოქიმიური კონვექციის წარმოშობის პირობებისა და აღმავალი ბუშტების (თერმიკების) წარმოშობის პირობების ვერტიკალური სიჩქარეების განსაზღვრისას გათვალისწინებულია განხილულ გარემოთა რეჟიმების სპეციფიკა. აღმოჩენილია $T(t)$ და $S(T)$ მრუდებზე უწყვეტობის მეორე რიგის დარღვევის წერტილები (დიაპაზონში $(40–80)^0$ C), რომლის მიღწევის შემდეგ (დასაწყისში წრფივი) მრუდი პარაბოლის გასწვრივ მიისწრაფვის დუღილის წერტილამდე 100^0 C. თერმოქიმიური კონვექციის დეტალები მოწმდებოდა კლასიკური კვლევების შედეგების ფონზე.