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Study of Georgian Natural Waters Thermodynamic Parameters Behavior by Means of Original Fluids Bubble Boiling Method

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Abstract

Some years ago the authors suggested new fluids bubble boiling method (BBM) for modeling vertical convection processes having place in the geospheres. Then they were developed in our recent articles for artificial solutions and analyzed by means of $T\ (t)$, $\Delta S\ (T)$, *and* $T\ (\rho)$ *experimental curves for definition of admixture of the mass content density of any solution or natural waters. In suggested article, luckily, were obtained optimal values of the liquid volume, the heating intensity, and temperature measurement frequency at any solution concentration allowed us, without waste of time and any trouble, to work out the original method BBM for modeling of above mentioned geophysical convective motions in the laboratory conditions and provide at that stage the planned experiments. Thus, it was investigated: the regimes of heating, the first smallest air-vapour micro-bubbles* ($d \approx 10^{-2}$ *cm), then macro-bubbles* ($d \approx 2 \cdot 10^{-1}$ *cm) boiling before the end of experiments* ($T = T_{max} = T \geq 100\ ^0C$)*. The experimental curves showed clearly the succession of the regimes: (1) thermal* ($T_0 = 10\ ^0C < T < T_1 = 40\ ^0C$)*; (2) microscale bubbles* ($T \leq T_1 = 40\ ^0C$)*; (3) macroscale bubbles* ($T \leq T_2 = 80\ ^0C$)*; (4) intensive, in the form of some winding vertical bubble-chains* ($80\ ^0C < T \leq T_3 = 100\ ^0C$)*; (5) bubble-projectile* ($T \geq T_3 = 100\ ^0C$ *). To the end of experiments, mean value of loss of liquid mass was equal to about 10 % of the whole mass. At last, it was constructed universal experimental curves, connecting the values of parameters of the liquids at the points of the boiling regimes, changed and obtained three linear curves* $T\ (t)$, $\Delta S\ (T)$, *and* $T\ (\rho)$, *and sinusoidal* $\Delta T\ (\Delta t)$ *one for natural waters of Georgia and artificial chemical matter solutions of any density at the points of the regime break.*

Unlike the Nu-Ra case, our BBM allows to experimenter for short time to determine main thermodynamic parameters, avoid technical difficulties of preparation, and carry out measuring, especially near the breaking points of the regimes, and recommend it to corresponding physical-chemical laboratories.

Keywords: vertical convection, incipience, one-dimensional, two-phase flow, temperature, entropy, points of discontinuity, Archimedes force, bubble boiling, vapour, beaker.

> Thermodynamic laws are empirical, therefore they
> may be considered with different ways, which are
> equivalent… It would be great mistake to be carried
> away mathematics and forget about physics. Ryogo Kubo.

Introduction

It is well known lots of scientific works devoted to the investigation of convective motions in different geospheres such as thermals and convective clouds, thermal waters, gazers, volcanos, many technical applications, sufficiently small scale geophysical phenomena, etc. [1-28]. Our laboratory experiments provided earlier on the water solutions of NaCl, $C_6H_{12}O_6$, other matters of different concentrations, and some natural waters of Georgia showed some new results [25-28]. The liquids bubble boiling method (BBM) have presented in the more complete form. New results analyzed in the context of the entropy change regimes allowed us to confirm their reliability. A work, as a priest gravity and Archimedes forces. The last part of the article is dwelled on the **optimal** characteristics of the modelled system – natural waters and artificial waters solutions – significant peculiarities of these simple models. One may say, that even this simplest case of one-dimension vertical motion reveals a **rich wealth** of considered phenomena.

II. Laboratory experiments

(a) Here are obtained and analyzed results of systematic laboratory experiments on the modeling of the vertical convection process and independent investigations of the thermodynamic parameters of the Georgian thermal waters by means of suggested original method BBM. The experiments, carried out on a samples of natural waters, are following: the spring of the Berebis Church (t. Tsalka); the Black Sea water (t. Anacklia); sulphuric waters (lake Lisi, Tbilisi); sulphuric waters (Bath-Houses, old Tbilisi); mineral waters (m/c Kazbegi); spring waters of m. Mtatsminda Pantheon (over Cap.Tbilisi) (according to the annals data, sacred waters sprang in the Mtatsminda Pantheon, thanks to the urgent prayers of the Pantheons priest, David Garejeli (VI a.Chr.))
Results of these experiments are illustrated in Figs. 1-5.
Fig. 1 shows thermodynamic picture of the Berebis Church drinking waters sample (t. Tsalka) on the basis of our bubble boiling method.

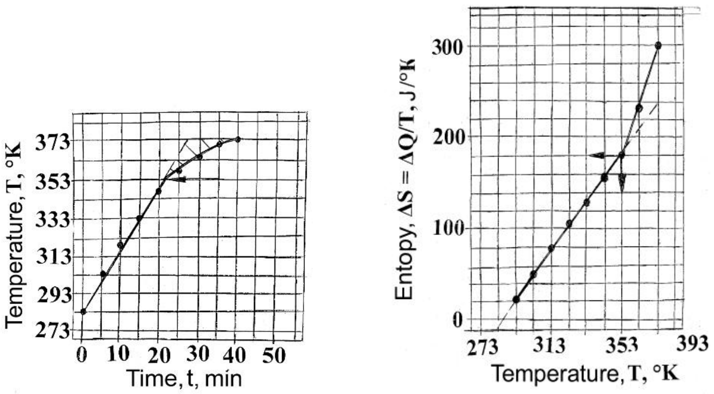


Fig. 1. A sample of the spring at the Berebis Church (t. Tsalka).

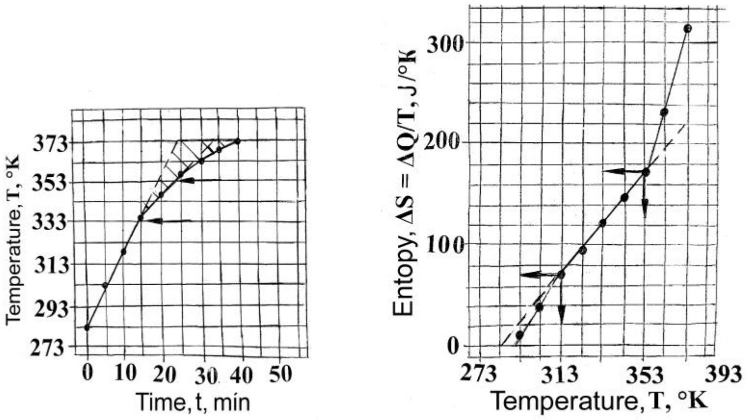
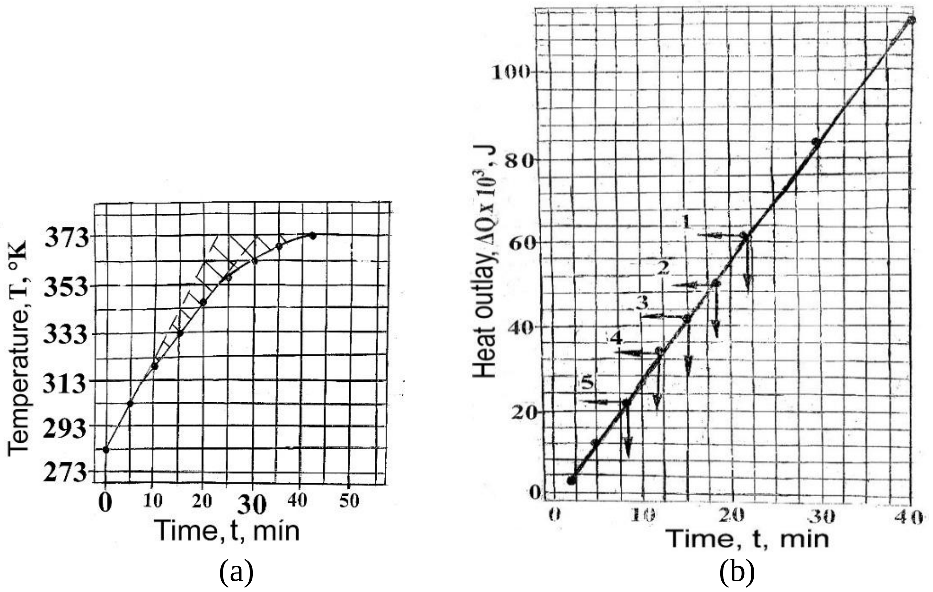


Fig. 2. The Lake Lisi sulphuric waters sample (Tbilisi)

Analogical result was obtained for the sulphuric waters sample of the old Tbilisi range (Abanoebis Ubani) by means of our bubble boiling method.

Results of constructions of dependence between the characteristics of studied natural waters at the breaking (changes of boiling regimes, kink when takes place large-scale vertical convection) points – the second kind discontinuities during the bubble boiling process (Figs. 1-5).

b. Special sample of well-known in Kakheti Region of Georgia, r/c Velistsikhe, a grapes juice – badaghi – natural glucose of different values of density.



(a) (b)

Fig. 3. Kakheti, t. Velistsikhe, (badaghi – $C_6H_{12}O_6$ solution): (a) – max density of glucose; (b) – outlayed heat against the time of heating of badaghi solutions.

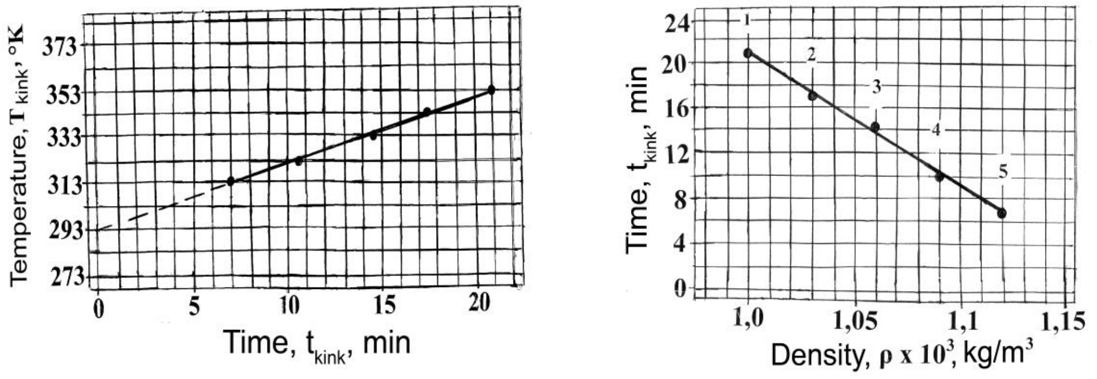
Fig. 3b shows the $\Delta Q(t)$ function for glucose water solutions of different densities. The points of change of bubble boiling regime are indicated by the **pair of pointers** (1, 2, 3, 4, 5). Experiments carried out by the bubble boiling method on artificial solutions and natural water samples showed that measuring of some parameter change gives us sufficiently full and precise information about the **changes of heating and bubble boiling regimes** values of respective bubble boiling temperature, density and other thermodynamic parameters of investigated object.

For example, the water solutions of NaCl and a honey of the same density (ρ = 1.03 g/cm^3) have equal values both of all three measured values of parameters (T, ρ, t) and calculated values of the entropy ΔS(T). Thus, the investigated fluid, having volume equal 300 ml, is heated from below; the temperature is measured in time, T(t), beginning from initial value, T(0), through all studies of formation of bubble boiling regime having fix the two by two points of the second kind of discontinuities ("kink", "break"), T_1 and T_2, before achievement of the last, most intensive bubble boiling, T_3 = 100 ^{0}C. After detail analysis of the results of these experiments we constructed two groups of the experimental curves, T(t), ΔS(T), and T(ρ): (a) – concrete values, and (b) – for the points of the discontinuity. These experimental curves have universal character. It is evident, that using suggested method, these universal experimental curves, one can determine unknown values of the density, characteristics of each stage of investigated liquids for modelling of vertical convection in nature: in the atmosphere, oceans, volcanoes, etc. It is necessary to note that investigation of this process, having great scientific interest, may be qualified as independent significant problem. In this light, suggested original simple and cheap method may recommend to physical and chemical laboratories.

III. Construction of universal curves at discontinuities thermodynamic main parameters.

The (T, t), (ΔS, T), and (t, ρ) experimental curves of (for any samples of liquids) investigated liquids helped us to obtain following results. (a) the temperature-time curves fix all points of bubble boiling regime change (break / kink) which are between **T = 40 ^{0}C** (solution with density $\rho \geq 1.2$ g/cm^3) and **T = 80 ^{0}C** (clear water, $\rho = 1$ g/cm^3) (see Figs. 1-5); (b) the entropy-temperature curves show only the latter point **T = 80 ^{0}C**; these curves, having make the others round, grow **linearly** before the point T = 80 ^{0}C and then, bending to the right, continue their grow to the **T = 100 ^{0}C**, but with diminishing rate (Figs. 1, 2, 5a).

Below, Fig. 4 represents the universal experimental curves connecting with each other the main thermodynamic parameters points of the second kind of discontinuity (kink, break)



(a) (b)

Fig. 4. Universal curves of the parameters characterizing the change of bubble boiling regimes:

(a) – $(T, t)_{kink}$; **(b)** – $(t, \rho)_{kink}$; **1**– spring of r/c Tsalka(21.5 min); **2**– Black Sea's water, t. Anaklia (17 min); **3** – sulphuric water of the Lisi Lake (14.5 min); **4** – sulphuric water of Tbilisi old region's bath-houses (11 min); **5** – honey solution (7 min).

The data of parameters of investigated liquids, presented above in Fig. 4, illustrate linear character of the functions (T, t) and (ρ, t) at the points of change of the bubble-boiling regime (usually noted by terms: "kink" or "break", or "discontinuity of the second kind") for any natural liquids or artificial solutions. Their corresponding empirical formulas have following :

$$T_{изл} = T_0 + \alpha t, \qquad T_0 = 19^0C, \qquad \alpha = 2.8^0C/min;$$

$$(\rho_{изл} - 1)/a + t_{изл}/b = 1, \quad a = 0.18\ g/cm^3, \quad b = 21.5^0C. \qquad (1)$$

Repeated boiling experiments with artificial water solutions or natural waters shoe that measured value of their any parameter (for example, $T_{kink}(t_{kink})$) gives us sufficiently right an d precise information about bubble-boiling regime and unknown parameter (for example, density, ρ) of studied liquids (natural/thermal/mineral waters).

For example, the water solutions of an edible salt (NaCl) and a honey ($C_6H_{12}O_6$) of the same volumetric density (ρ = 1.03 g/cm^3) on the curves $T_{kink}(\rho_{kink})$ and $T_{kink}(t_{kink})$ have the same reading of experimentally measured values of three parameters (T, ρ, t) and calculated values of entropy, $\Delta S_{kink}(T_{kink})$. Full picture give the control experiments on the specially prepared samples of water solutions of a honey with following proportion ((1:2:3:4:5) g) / (300 g of water) confirmed once more obtained earlier (Fig. 3 in [26]) conformity to natural laws (T_{kink} /ρ_{kink}):

$80^0C/1.0\ g/cm^3;\ 70^0C\ /1.02\ g/cm^3;\ 60^0C\ /1.07\ g/cm^3;\ 50^0C\ /1.08\ g/cm^3;\ 40^0C\ /1.27\ g/cm^3.$ (2)

Thus, suggested bubble boiling method allows us during ~ 50 min obtain a density, temperature, entropy, intensity of heating any solution at the points of change of the thermal-bubble-boiling regimes, respectively by means of the system experimental curves.

IV. Heating of fluids from below – fast straight absorption process.

Using equality of the heating flux through the bottom of the vessel

$$dQ = \lambda\ (T_k - T)/\delta\ Sdt, \qquad (3)$$

to the quantity of the heat dQ = mc dT, spent on the heating of the m mass of liquid, we obtain the simple differential equation

$$\lambda\ (T_k - T)/\delta\ Sdt = mc\ dT, \qquad (4)$$

at the conditions:

$$t = 0,\ T = T_0;\ t = \tau,\ \ T = T_{k,} \qquad (5)$$

where T_k is a temperature of the bottom of the chemical vessel, λ – is the vessel's material thermal conductivity, δ and S are the thickness and the square of the vessel's bottom, respectively; the temperature homogeneity at the whole bottom surface was achieved by means of thin metallic plate between the vessel's bottom and an electric stove. Analytical solution of differential equation (4) is

$$T(t) = T_k + (T_0 - T_k)\ e^{-(\lambda S/\delta mc)t}\ . \qquad (6)$$

Formula (6) describes initial stage of heating of fluid as a solid body, where a heat conductivity prevails over convection and, of course, latter is absent, a circumstance expressed by means of an exponential multiplier of formula (6); the first and third addendums of equation (4) consider as most important ones. Using numerical values of parameters given in (11), one obtains for exponent:

$$\lambda S/\delta\ mc = 0.007 \cdot 11.9/0.3 \cdot 300 \cdot 4.19\ s^{-1} = 7 \cdot 10^{-7}\ s^{-1} \approx 0. \qquad (6')$$

Temperature of liquid achieves the point $T = T_k = 100^0$C. This is a process **of heating of liquid** modelled by means of criterions of similarity **Fo** and **Pe,** and in case of its **boiling** – with **Nu** and **Ra,** [9, 15-18]. Here we note, that construction of experimental curves $(T, t)_{kink}$, $(\Delta S, T)_{kink}$, and $(T, \rho)_{kink}$ allowed us to obtain some new results on the physical properties of the investigated fluids (natural waters, sea water, artificial solutions etc.). They are following: changing of regimes (at the surface of beaker's bottom T ~ 108 ^{0}C) – over the bottom of beaker thermals (20 ^{0}C), microscale bubble boiling (40 ^{0}C), macroscale bubble boiling (80 ^{0}C), intensive heavy turbulent in form of vertical bubbles pillars (100 ^{0}C), saturated vaporization (100, 8 ^{0}C).

V. Loss of heat by fluid – slow reverse process. Let us consider heat conduction, Q, through lateral cylindrical wall of a beaker

$$Q = \lambda \frac{T - T_a}{d} D, \qquad (7)$$

where λ is coefficient of heat conduction of beaker's lateral wall; d – thickness of beaker's lateral wall; D – square of beaker's lateral wall; T – temperature of beaker-liquid system); T_a – temperature of laboratory air (constant during experiment at open window).
In more concrete, Fourier law, form, of beaker's

$$Q = -\lambda \frac{dT}{dr} 2\pi Rh, \qquad (8)$$

where dT/dr is temperature gradient in cylindrical wall of the beaker; R is a radius of the beaker's circle bottom; h is thickness of liquid's layer in a beaker.
Consider two cases of boundary conditions:

(a) $dT / dr < 0$, $(T < T_a)$

$$Q_1 = mc\,\Delta T + \Delta m\,L + \lambda \frac{dT}{dr} 2\pi Rh + Mc'\Delta T; \qquad (9)$$

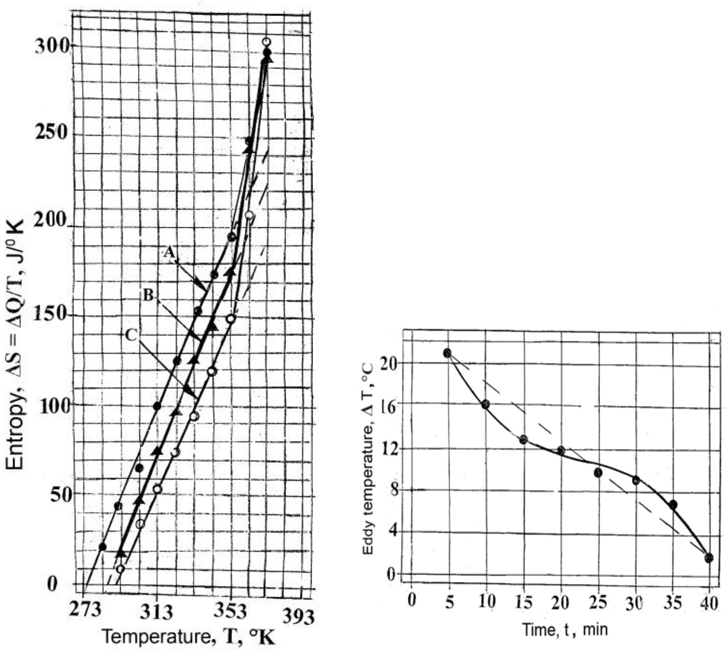
(b) $dT / dr = 0$ (cylindrical wall is isolated),

$$Q_2 = mc\,\Delta T + \Delta m\,L + Mc'\Delta T, \qquad (10)$$

where M is the mass of the glass; $c' = 0.779$ J / (g · K) is the glass heat capacity; usual glass $\lambda_1 = 0.7$ J / (m · s·K) = 0.007 J / (cm · s · K); quartz glass $\lambda_2 = 1.36$ J / (m · s·K) = 0.0136 J / (cm · s · K); $\Delta T = 90^0$C; d = 0.3 cm; $S = \pi R^2 = 37.37$ cm^2, h = 8 cm, m = 300 g; Δm = 30 g; $R_{bot} = 3.45$ cm; ρ = 1 g / cm^3; c = 1 cal / g · K = 4.19 J / (g · K); $L = 2.25 \cdot 10^3$ J / g; $W_0 = 103$ J / s, $W_{bot} = 47$ J / s. (11)

VI a. Peculiarity of behavior of the liquid temperature under their heating at different intensity.

Changing rates of liquids heating process we determined relation between scales of parameters of studied liquids – time intervals (Δt); temperature interval (ΔT); mass of liquid (Δm); form and size of beaker (cylinder, ΔV); interval of solution density (Δρ); intensity of heating (q). Obtained values are following: Δt = 5 min; ΔT = 5 ^{0}C; Δm = 300 g; $\Delta V = 10^3$ cm^3; $\Delta\rho = (1 \div 1.2)$ g cm^{-3}; q = 47 J s^{-1}.



(a) (b)

Fig. 5. **(a)** – entropy-temperature dependence, ΔS (T); (b) – temperature-time, ΔT (t), dependence at the heating intensity, respectively: q = 35 J/s (low branch), q = 47 J/s (intermediate branch), and q = 75 J/s (upper branch); **(b)** – the sinusoidal temperature-time dependence ΔT (t), obtained for every successive time interval Δt = 5 min, at the intensity of heating q = 47 J/s).

The empirical formula of the temperature-time dependence**,** T (t), for the r/c Tsalka natural thermal waters sample has following sinusoidal form:

$$T(t)_{emp} = T_0 + (T_b - T_0)\ (t/\tau)\ \bar{A}\ \sin 2\pi(t/\tau)\,, \qquad (12)$$

where $\bar{A} \approx 2$ ⁰K and $\tau = 35$ min are the mean value of the amplitude and the period of sinusoidal change of temperature, respectively; T_0 and T_b are the initial temperature and the point of boiling of liquid, respectively.

It was possible to measure the average temperature during providing of experiment with an accuracy to ± 1 ^{0}C by using of both optimal quantity mass of solution and time interval of measuring. The latter was in following: the mass of a liquid was approximated to the m = 300 g = 300 ml which boiled between 40 min with intensity, water and time interval about nine points between laboratory temperature T_0 = 10 ^{0}C and then as initial constant one before beginning of every experiment (by using refrigerator). As it is was shown in this work, whole process of thermodynamic state of liquids, heating from below, is characterized, quantitatively, and, as well as qualitatively, by temperatures T_0 = 10 ^{0}C, $T_{1,\,kink}$ = 40 ^{0}C, $T_{2,\,kink}$ = 80 ^{0}C, T_b = 100 ^{0}C, T_{bot}, and T_{up} – overheating of fluid at the rigid bottom of the vessel and free upper surface of liquid, respectively.

Fig. IA shows that the curves: **(a)** ΔS (T), and sinus **(b)** ΔT (Δt), reveal only one point of the second kind of discontinuity (at 80 ^{0}C = 353 ^{0}K). Only the entropy displays effective growth with temperature ΔS(T) (at different intensities of heating of liquid, q),

VI b. Energetic characteristics of liquids bubble-boiling process obtained in laboratory.

The Table 1 shows data obtained on the base of optimal values of parameters of the thermodynamic system (samples of studied waters): q = 47 J – the intensity of an electrical source; m = 300 g – the mass of a liquid; V =10^3 cm^3 – the volume of a beaker; ΔT = 5 ^{0}C; Δt = 5 min.

Table 1. Energetic characteristics of heating of clear thermal water from r/c Tsalka
(q = 47 J/s, m = 300 g, V = 10^3 cm^3, ΔT = 5 ^{0}C, Δt = 5 min)

T, ^{0}C	t, min	Heat quality, Q_n, J	Share of Q_n/Q,	Q_n/Q, %
10	0	–	–	–
40	9	25320	25320/112800	22.5
80	21.5	35310	35310/112800	31.3
100	40	52170	52170/112800	46.2

VII. Fragments from discussion of known numerical modeling of large-scale convective motions in atmosphere and ocean [22].

During intensive and heavy turbulent boiling part of liquid, the entropy **curve** increase shows slowing-down to the end of experiment; that means that heat energy spends almost completely for evaporation of liquid. The following quotations from article [22] as we think would be very useful and relevant at discussion of results of our experiments: **(1)** Two general expressions are derived for a rate of entropy production due to thermal and viscous dissipation (turbulent dissipation) in a fluid system. It is shown with these expressions, that maximum entropy production in the Earth's climate systems suggested by Paltridge, as well as maximum transport properties of heat or momentum in a turbulent system suggested by Malkus and Busse, correspond to a state in which the rate of entropy production due to the turbulent dissipation is at a maximum…For **thermal convection** of a fluid layer **heated from below** (our case), Malkus (1954) suggested that the observed mean state represents a state of maximum convective heat transport. For **turbulent flow** of a fluid layer **under a simple shear,** Malkus (1956) and Busse (1970) suggested that the realized state corresponds to a state with a maximum rate of momentum transport. **(2)** Two developments should be mentioned here. One is a theoretical investigation of MEP (maximum entropy production) based on statistical interpretation of entropy (Dewar, 2003). Information theory (Jaynes, 1957) showed that the most probable macroscopic steady state is one with MEP among all other possible states, given the boundary conditions and mass and energy conservation laws. This statistical approach will broaden the horizons between MEP and information theory (Lorenz, 2002, 2003). It will also be a theoretical basis for the energetic explanation shown above since the between the heat energy and the kinetic energy is only of statistical significance. That is, spontaneous conversion of the heat energy into the kinetic energy is in principle possible, but is just extremely improbable. **(3**) Another development has been made with numerical model simulations: (a) numerical experiments on Bénard-type experiments of thermal convection in a rotating fluid system – obtaining **a kink in the rate of entropy production between two different convection regimes.** One founded that irreversible changes always occur in the direction of the increase of entropy production (see [22]) (compare with our experimental results, Figs. 1-5, !).

VIII. Heating balance of the liquids' bubble boiling process.

Defined more precisely with additional information, the method allow better understand both the peculiarities of liquids bubble boiling kinetics and their regimes changing high rate:
(1) thermals (at $T_0 = 10\ ^0C < T < T_1 = 40\ ^0C$); (2) microscale bubbles (at $T \leq T_1 = 40\ ^0C$); (3) macroscale bubbles (at $T \leq T_2 = 80\ ^0C$); (4) intensive, in the form of some winding vertical bubble-chains ($80\ ^0C < T \leq T_3 = 100\ ^0C$) – wellknown in literature intermediate structure – "bubbly-slug flow" [13] ; (5) bubble-projectile ($T \geq T_3 = 100\ ^0C$), [13],
It is suggested improved defined more precisely simple laboratory method of definition of admixture density of any fluids or water solutions. We can determine a degree of **purity** of liquids using experimentally obtained universal curve $T_{kink}(\rho_{kink})$ (see Fig. 3, [26, 25]), (lower mark "kink" was used by Ozawa et al. [22]). Results of constructions of dependence between the characteristics of natural waters or artificial solutions at the breaking points (changing of boiling regimes) show a linear character of all experimental curves $(T, t)_{kink}$, $(\Delta S, T)_{kink}$, $(t, \rho)_{kink}$. As a rule, the term "breaking" is used in thermodynamics and special literature (for example, cited here, [5, 7, 10, 13, 19, 30, 31]), the authors of article [22] use term "kink" to the change of large scale thermal convection regimes in atmosphere and in oceanic general circulation, [32].
Latter data are in accordance with our modelling results (Figs. 1-5).

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საქართველოს ბუნებრივი წყლების ძირითადი თერმოდინამიკური პარამეტრების ყოფაქცევის შესწავლა სითხის ბუშტოვანი დუღილის ორიგინალური მეთოდით

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რეზიუმე

უკანასკნელ წლებში ავტორების მიერ შემუშავებული ბუშტოვანი დუღილის ორიგინალური მეთოდი საშუალებას იძლევა ლაბორატორიული წყალხსნარების და ბუნებრივი თერმალური (მინერალური) წყლების მახასიათებელი პარამეტრების – სიმკვრივის, ტემპერატურის, ენტროპიის და დროის მომენტების – ურთიერთ კავშირის დადგენა დუღილის რეჟიმის გარდატეხის წერტილებში მოცემული უნივერსალური ექსპერიმენტული მრუდთა სისტემის მეშვეობით.

მიღებულია ოპტიმალური შეფარდებები საკვლევი სითხის მოცულობასა და მიწოდებული სითბოს ნაკადის ინტენსივობის შორის. კონტროლირდება ბუშტების წარმოშობის პროცესი სათანადოდ მიკრო-მასშტაბური რადიუსის $R \leq 10^{-2}$ სმ ზომიდან მაკრო-მასშტაბური რადიუსის $R \geq 0.2$ სმ სმ ზომამდე. დადგენილია ექსპერიმენტული მრუდების გარდატეხა (უწყვეტობის მეორე გვარის წყვეტა) $T = 40 - 80^0$ C ინტერვალში. მიღებული ექსპერიმენტული მრუდები $T(\rho)$, $T(t)$, $\Delta S(T)$ და დეტალური ცხრილები სრულ ინფორმაციას იძლევა თერმოდინამიკური სისტემის სიმკვრივესა და სხვა მახასიათებელი პარამეტრის შესახებ. გაანალიზებულია ენტროპიის მნიშვნელობა სითხის დუღილის რეჟიმების ცვლილების მომენტების დაზუსტებაში, რომლებიც ტემპერატურის დროში $T(t)$ მრუდების მეშვეობითაა დადგენილი, განსაკუთრებით მხურვალე ბუშტოვანი დუღილის პროცესის ტემპერატურის $80 - 100^0$ C ინტერვალში. აქ ადგილი აქვს ბუშტების ჯაჭვისებრი მდგრადი ვერტიკალური კლაკნილი სვეტების სახით მხურვალე ინტენსიური დუღილი. მიღებული ექსპერიმენტული მრუდები საშუალებას იძლევა თერმოდინამიკური მდგომარეობის რეჟიმების და მათი ცვლილების შემდეგი თანმიმდევრობით განხილვა: **(1)** – თვალით უხილავი, თავისუფალი კონვექციის (თერმიკული) რეჟიმი, ტემპერატურის $T_0 \geq 0^0$ C $< T_1 \leq 40\ ^0$ C ინტერვალში; **(2)** – მცირე ზომის ბუშტოვანი ($R_1 \leq 10^{-2}$ სმ) დუღილის რეჟიმი, $T \leq T_1 = 40\ ^0$ C ინტერვალში; **(3) –** $R_2 \leq 10^{-1}$ სმ რადიუსის მქონე ბუშტოვანი დუღილის რეჟიმი, $T \leq T_2 = 80\ ^0$ C ინტერვალში; **(4) –** $2{\cdot}10^{-1} \approx R_3 > 10^{-1}$ სმ რადიუსის მქონე ინტენსიური ბუშტოვანი დუღილის რეჟიმი, $T_2 = 80^0$ C $< T < T_3 = 100^0$ C ინტერვალში;

(5) –- ბუშტოვან-ჭურვისებრი დუღილის რეჟიმი, სითხის ტემპერატურის $T \geq T_3 = 100\ ^0$C ინტერვალში; ექსპერიმენტის დასასრულს სითხის მასის დანაკლისი, Δm, საშუალოდ შეადგენდა მთელი მასის 10 % -ს ($\Delta m \approx 30$ გ.). შემდგომი: **(6)** – დისპერსიული და **(7)** – ორთქლისებრი დუღილის რეჟიმების შესწავლა არ შეადგენდა პროგრამის საგანს.

მეთოდი საშუალებასიძლევა საკმაოდ სწრაფად და ზუსტად დადგინდეს ნებისმიერი ნივთიერების წყალხსნარის სიმკვრივე, ტემპერატურა, ენტროპია, დრო, სითბოს ინტენსივობა დუღილის რეჟიმების გარდატეხის წერტილებში, შრომატევადი Nu-Ra მრუდების აგების აუცილებლობის გარეშე. და ბოლოს, მეთოდის სიიაფე და სიმარტივე იმედს იძლევა რეკომენდაცია გაეწიოს სხვადასხვა დონის სასწავლო და ფიზიკა-ქიმიურ კვლევით ლაბორატორიებს გასაცნობად.

Исследование основных термодинамических параметровприродных вод Грузии оригинальным методомпузырькового кипения жидкости

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Резюме

Получены универсальнаые экспериментальные кривые для определения плотности содержания примеси в жидкости любого раствора или естественных термальных вод оригинальным методом пузырькового кипениях. Получены оптимальные соотношения между объёмом исследуемой жидкости и интенсивностью подаваемого теплового потока. Контролируется процесс появления пузырьков от мельчайших (микромасштабных) размеров, диаметром порядка 10^{-2} см, до крупных ~ 0,2 см. Установлено по-парное существование разрывов непрерывности второго рода в интервале (40-80) ^{0}C. Полученные экспериментальные кривые, T (ρ), T (t), and ΔS (T), и детальные таблицы дают полную информацию о плотности термодинамической системы и других её характерных параметрах. После T(t) вступает в роль ΔS (T) в установлении моментов смены режимов кипения жидкости, в особенности во второй половине процесса бурного пузырькового кипения в виде устойчивых извивающихся вертикальных цепей пузырьков пар-воздух (впечатляющих “пузырьковых шлангов”!).

Экспериментальные кривые наглядно обнаруживают смену режимов: (1) – режим свободной конвекции (термиковый, от 0 ^{0}C до 40 ^{0}C (2) – режим мельчайших газовых пузырьков при $T \leq T_1 = 40\ ^0C$; (3) – крупнопузырьковый режим с ярко выраженным изломом T (t) и ΔS (T) кривых при $T \leq T_2 = 80\ ^0C$; (4) – режим бурного крупно-пузырьковогого кипения в виде ряда вертикальных цепей, столбиков в интервале температур 80^{0}C - 100^{0}C; (5) – режим пузырьково-снарядного кипения при $T_3 = 100\ ^0C$; (5) – режим пузырьково-снарядного кипения при $T_3 = 100\ ^0\ C$; в среднем к концу экспериментов – с 10 %-й убылью всей массы жидкости (Δm 30 г.). Последующие режимы: (6) – дисперсный и (7) – парообразования, не входили в программу настоящих исследований.

Метод позволяет за короткое время достаточно точно определить плотность, температуру, энтропию, интенсивность нагрева водного раствора любого вещества в переходных точках режимов кипения, обойти трудоёмкие построения Nu-Ra кривых. Наконец, простота и дешевизна разработанного метода позволяет рекомендовать его разного уровня учебным и исследовательским физико-химическим лабораториям для ознакомления.