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Additional experiments on the study of peculiarities of clear water, H_2O, and both water sugar, $C_{12}H_{22}O_{11}$, and edible salt, NaCl, solutions of maximal densities by means of original fluids bubble boiling method

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Abstract

There are considered results of the laboratory works which continue the modeling of vertical convective motions in different geophysical fluids (theoretically) and (experimentally) – in artificial and natural water solutions – by means of suggested before original fluids bubble boiling method (FBBM)[1, 2]. Using the edible salt and sugar water solutions, peculiarities of their temperature-density, T(ρ), temperature-time, T(t), entropy-temperature, ΔS(T), and heat intensity-time, Q′(t), functional dependences were investigated experimentally, in detail. Three characteristic values of temperature of the bubble boiling regime change, T (H_2O) = T($C_{12}H_{22}O_{11}$) = 40^0C, 80^0C, 100^0C and T(NaCl) = 40^0C, 80^0C, 108^0C, were found, respectively. These values were obtained on the base of detail experiments for accessible intervals of densities (minimal-maximal) equal, respectively: Δρ(NaCl) = (1.01–1.2) g cm^{-3} и Δρ($C_{12}H_{22}O_{11}$) = (1.04 –1.47) g cm^{-3}. Experimental curves T(ρ), T(t) and ΔS(T), as a rule, in the temperature interval ΔT = 40^0C – 80^0C undergo the discontinuity of the second kind. They allowed us to establish the law of appearance of the points of the second kind discontinuities. Obtained T(ρ), T(t) and ΔS(T) experimental curves (Figs. 1-6) have universal character, are independent on the substrate's nature and initial temperature of the researched solutions. They give sufficiently full information about new results of provided experiments, which may have not only applied meaning. It is necessary to emphasize an importance of obtained experimental dependences, (T(ρ), T(t), ΔS(T), and Q′(t)) from the point of view of opening perspectives of development and deepening of suggested method both to avoid superfluous technical efforts quickly and without error, find main characteristics of investigated fluids.

I. Introduction.

In this report, new results of experimental research of vertical one-dimensional two-phase flow, modeling natural convective processes according to the original fluids bubble boiling method

(FBBM) suggested by us in works [1, 2]. These laboratory modeling experiments are further continuation of above mentioned investigations of fluids vertical convective motions.

The character values of studying thermodynamic system, such as dependences: temperature-heating time, T(t); entropy-temperature, ΔS(T); hysteresis curves, $T^{+}(t)$-$T^{-}(t)$, ("+"and "– " signs correspond to heating and cooling of fluids, respectively), are represented in Figs. 1-6 and Table 1. Each of Figs. 1-5, both for convenience of analysis and limitation of place, simultaneously contains two by two graphs: upper –constrained by means of net experimentally measured data, T(t); lower – on the base of calculated characteristics of system, ΔS (T). It is necessary to note, that analogical laboratory modeling vertical one-dimensional geophysical convective flows in literature practically are absent ([6, 7, 1, 2], see also refs in [1]).

II. Method and results of the experiments.

Both graphs, T(t) and ΔS(T), in Fig.1 for clear water have a second kind of discontinuity at temperature $T_1 = 80^0$C, connected with bubble boiling point [1, 2]. The temperature is achieved (in conditions of our experiments, at intensity of heating about 15 cal/min flux) after the lapse of 25 min from the initial temperature of $T_0 = 10^0$C.Experiments provided on investigated water solutions of different materials showed that on the background of the curves of T(t) and ΔS(T) appear a new additional point of the second kind of discontinuity at more low temperatures. The entropy curve, ΔS (T), of NaCl maximal density water solution (ρ_{max} = 1.2 g cm^{-3} (see Fig. 5, where the entropy curve has two points of the second kind of discontinuity at $T_1 = 80^0$C and $T_2 = 40^0$C, respectively) exactly just so behaves, as T(t) one. In common with the results of our previous works [1, 2], and by the present ones it was experimentally established, that any substance water solutions curves, T(t) and ΔS (T), have two points of the second kind discontinuity ($T_1 = 80^0$C and 40^0C < T_2 < 80^0C) – for solution densities ($\rho_{max} > \rho_s > 1.0$ g cm^{-3}) (see Figs. 1-5).

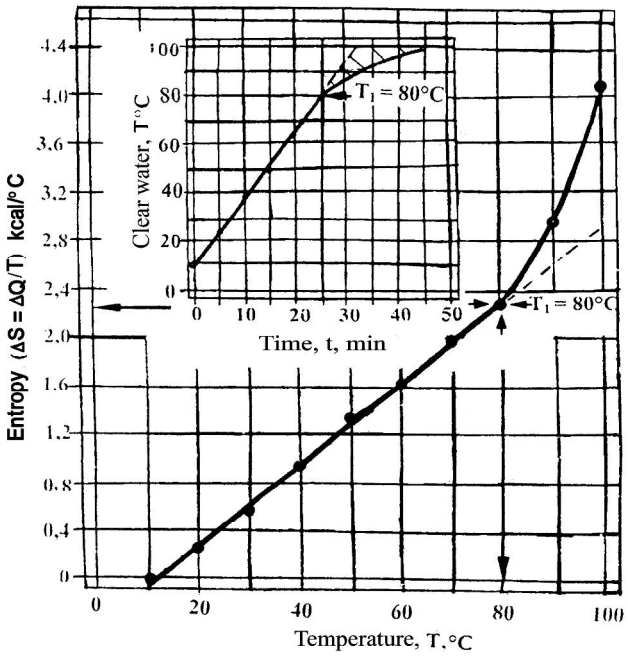

Fig. 1. Above – temperature-time dependence, T(t); lower – entropy-temperature dependence, ΔS(T), of clear water of density, ρ = 1.0 g cm^{-3}, heating from 10^0C up to 100^0C.

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Fig. 2 illustrates results of experiments on the sugar, $C_{12}H_{22}O_{11}$, water solutions of density ρ = 1.08 g cm^{-3}. As is seen, both curves, T(t) and ΔS(T), have two by two points of the second kind discontinuities at temperatures $T_1 = 80^0$C and $T_2 = 60^0$C, respectively. It is interesting to note that the NaCl water solution of the same density, ρ = 1.07 g cm^{-3}, has analogical readings (see Fig. 5).

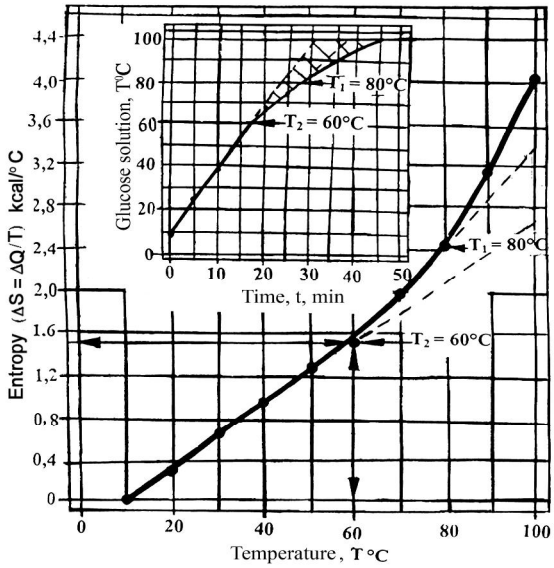

Fig. 2. Above – temperature-time dependence, T(t); lower – entropy-temperature dependence, ΔS(T), of sugar, $C_{12}H_{22}O_{11}$, water solution (ρ = 1.08 g cm^{-3}), heating from 10^0C up to 100^0C.

Fig. 3 corresponds to the the maximal density (ρ = 1.47 g cm^{-3}) sugar, $C_{12}H_{22}O_{11}$, water solution, heating from below at initial temperature $T_0 = 10^0$C. After 6 min (see Table 1 in [2]), it is achieved the sugar solution bubble boiling temperature $T_2 = 40^0$C, and then, after 24 min, – the sugar solution intensive bubble boiling temperature invariably equals to $T_1 = 80^0$C. The entropy, as a rule, undergoes both discontinuities at $T_2 = 40^0$C and $T_1 = 80^0$C, too.

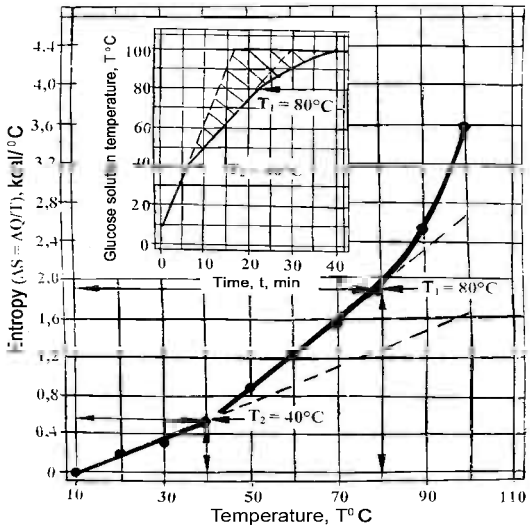

Fig. 3. Above – temperature-time dependence, T(t); lower – entropy-temperature dependence, ΔS(T), of sugar, $C_{12}H_{22}O_{11}$, water solution (ρ = 1.47 g cm^{-3}), heating from 10^0C up to 100^0C.

Fig. 4 shows the curves of T(t) and ΔS(T) for light NaCl water solution (ρ = 1.07 g cm^{-3}). Here, saying figuratively, the same past the baton of two points of the second kind discontinuities (T_1 = 80^0C and T_2 = 60^0C) to NaCl and other substances (see, present Figs. 1-3, and [1, 2]).

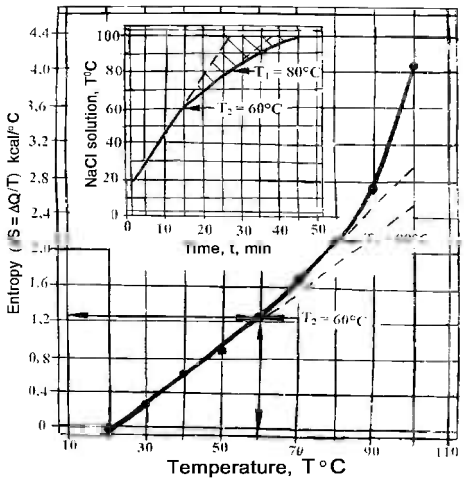

Fig. 4. Above – temperature-time dependence, T(t); lower – entropy-temperature dependence, ΔS(T), of NaCl water solution (ρ = 1.07 g cm^{-3}), heating from 20^0C up to 100^0C.

In Fig. 5, it is recurred the same very interesting property – availability of two points of the second kind discontinuity on the curves T(t) и ΔS(T). Here it was used the same NaCl water solution, but of the maximal density (ρ = 1.2 g cm^{-3}), having two limit values of solution bubble

boiling points $T_1 = 80^0C$ и $T_2 = 40^0C$ (!), as in the case of the sugar water solution of maximal density (see above and [1, 2]).

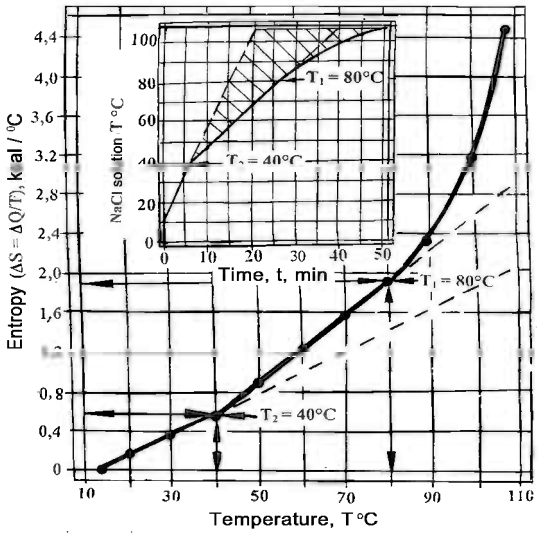

Fig. 5. Above – temperature-time dependence, T(t); lower – entropy-temperature dependence, ΔS(T), of NaCl water solution ($\rho = 1.2$ g cm^{-3}), heating from 10^0C up to 100^0C.

Fig.6 shows results of detail measuring during heating to the bubble boiling and then reverse motion of both curves (H_2O and $C_{12}H_{22}O_{11}$ solution of maximal density, $\rho = 1.47$g cm^{-3}). There are two points of crossing curves at temperature $T_3 = 100^0C$ (Figs. 6a, 6b) and lower at $T_2 \approx 62^0C$ (Fig. 6a). In case of clear water, H_2O, time of heating from 20^0C to 100^0C equals to 45 min; coordinates of the second kind discontinuity are following $T_1(80^0C$, 25 min); coordinates of point of boiling are – $T_3(100^0C$, 45 min). In case of sugar, $C_{12}H_{22}O_{11}$, time of heating from 20^0C to 100^0C equals to 40 min; coordinates of the second kind discontinuity are following $T_2(40^0C$, 5 min); coordinates of point of boiling are – $T_3(100^0C$, 40 min).

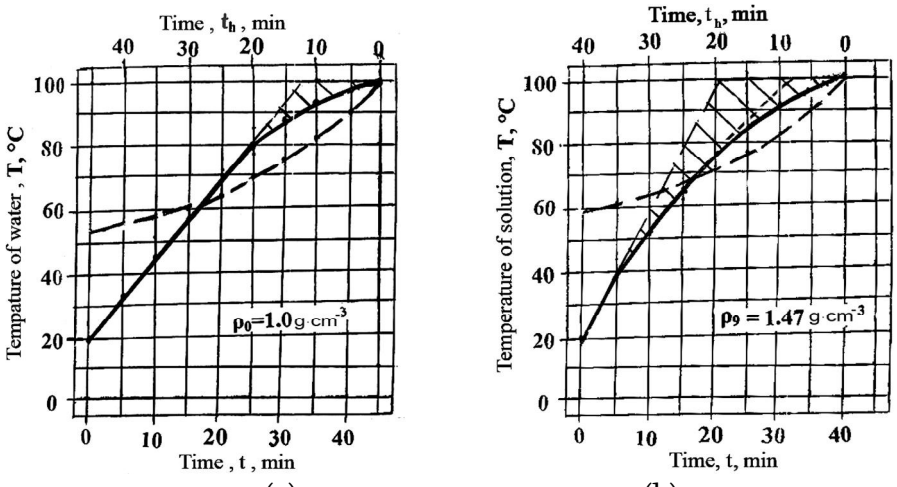

Fig. 6. The clear water (a) and sugar solution (b) bubble boiling

(solid lines, time scale – below) and hysteresis (dashed lines, time scale – above) curves. Heat flux, $Q'(t) \approx 15$ cal s^{-1}.

Unlike the water solution of NaCl (with maximal density $\rho = 1.2$ g cm^{-3}, and temperature of boiling $T_3 \approx 108^0$C), in case of sugar water solution ($C_{12}P_{22}O_{11}$), a rise of boiling temperature doesn't occur, and its boiling temperature $T_3 = 100^0$C. In case of sugar water solution of maximal density ($\rho = 1.47$ g cm^{-3}), the hysteresis square (ΔD_h) between solid line an dashed one, directed in the opposite direction (of low cooling process of the solution from the point of boiling $T_3 = 100^0$C) before their crossing with each other equals to, respectively: (a) for clear water ($\rho = 1.0$ g cm^{-3}) hysteresis square ΔD_h (H_2O) ≈ 3.5 sq. un., coordinates of this point are following (see Fig. 6a): $T_h \approx 62^0$C, and corresponding time of cooling, $t_h = 28$ min; (b) for sugar solution of maximal density $\rho = 1.47$ g cm^{-3}, $\Delta D_h(C_{12}P_{22}O_{11}) \approx 2$ un. sq.; coordinates of this point are following (see Fig. 6b): $T_h = 68^0$C, and corresponding time of cooling, $t_h = 23$ min; ratio between hysteresis squares of sugar and clear water $\Delta D_h(C_{12}P_{22}O_{11})$: ΔD_h (H_2O) $\approx 4:7$.

III. Analysis and discussion.

It is necessary to note, at once, that the results of measuring of character parameters of considered solutions in the most complete form represent in Fig. 6 a,b (during of heating: T_1, T_2, T_3; ΔS_1, ΔS_2, ΔS_3; t_1, t_2, t_3; during cooling – hysteresis parameters: ΔD_h, T_h, t_h).

On the derivation of initial linear parts of T(t)-curves at achievement of the points of the second kind of discontinuities – to the side of decrease along elliptical curve (when a heat is spent during a bubble boiling process); in case of the ΔS (T)-curves the initial linear character of growth of the curve, after the points of the second kind of discontinuity, is continued in the form of growing parabolic curve. In the solutions, such picture is repeated twice because of appearance the second analogical point of discontinuity. Increasing of the entropy curves growth temp is accounted for its inverse proportionality to the temperature of solution. Here it is also necessary to take into consideration that we have dealings with associated fluids (in particular, the water belongs to them, too), at heating of which, except of formation of bubbles of vapour, a part of the heat is spent in addition for dissociation of molecules, and, as a result, – the second kind of discontinuities in all curves T(t) and $\Delta S(T)$ (Fig. 1-6).

The vapours bubbles, generating into the fluids during boiling, are under hydrostatic pressure of column of water, surface of water curvature, and atmospheric pressure. To not to be crushed, the bubble must contain sufficiently high value of saturated vapour pressure in order to resist of whole external pressure. But, as is known, inside of the bubble, because of concave surface, the pressure of saturated vapour is less, than over a plate surface, and the smaller than the smaller of bubbles radius, too. Because the bubble boiling process begins from generation of very small size bubbles ($r = 10^{-7}$ cm), then this insufficiency of the pressure inside of the bubble reaches considerable value, and the bubble of air fast becomes flat and disappears. In the volume of heating fluids, huge accumulation of the smallest bubbles slowly moves vertically upwards, under action of Archimedes force. The boiling does not begin, although from the outside of the liquid the conditions of the boiling are available. When temperature of liquid at the bottom of the vessel is increased, the vapour bubbles of size $r \sim 10^{-4}$ cm suddenly quickly growth at the temperatures (T_1 and T_2) of the

second kind discontinuity. In case of clear water $T_1 = 80^0C$, and in case of different substance solutions the temperature of discontinuities is between $T_2 = 40^0C$ and 80^0C, and following growth of liquids temperature and completing very intensive bubble boiling temperature $T_3 = 100^0C$ (for clear water, H_2O, and for the water solution of sugar, $H_{12}C_{22}O_{11}$, of maximal density $\rho = 1{,}47$ g/cm^3) и $T_3 = 108^0C$ (for NaCl water solution of maximal density, $\rho = 1{,}2$ g/cm^3), intensive boiling in form of stable vertical columns of lengthened bubbles, which maybe named "hose" – boiling.

IV. Conclusion.

Thus, obtained experimental curves $T(\rho)$, $T(t)$ and $\Delta S(T)$ (Figs. 1-6) (or the bubble boiling method):

(1) – have universal character are independent on the substrate's nature and initial temperature of the researched solutions; (2) – allow one to establish the law of appearance of the points of the second kind discontinuities; (3) – give sufficiently full information about new results of provided experiments; (4) – may have independent and not only applied meaning; (5) – are significant from the point of view of opening perspectives of development and deepening of suggested method; (6) –the method allows also to avoid superfluous technical efforts, quickly and without error, find main thermodynamic parameters of investigated solutions.

References

[1] Gvelesiani A.. J. On the one-dimensional two-phase/many-component convective flows in different geophysical mediums: laboratory method of modeling of fluids bubble boiling. Georgian Geophys. Soc., 2013, v.16B, pp. 119-128.

[2] Gvelesiani A., Chiabrishvili N. Laboratory modeling of thermals generation in geophysical environments by means of fluid bubble boiling method. J. Georgian Geophys. Soc., 2013, v.16B, pp. 129-137.

[3] Gvelesiani A. Open thermodynamic systems: some new aspects of convection processes modeling by fluids bubble boiling laboratory method. J. Georgian Geophys. Soc., 2014, v.17B, pp. .

[4] Bunn Ch. Crystals. The role in nature and in science. Academic Press. New York – London, 1964 (Чарлз Банн. Кристаллы. Их роль в природе и науке. М.: Мир, 1970, 312 с.)

[5] Pavlov V. I. Mechanics. Molecular Physics. M.: GTTL, 1955, pp. (265-266), 356. (in Russian)

[6] Jellinek A. M., Manga M. Links between long-lived hot spots, mantle plumes, D″, and plate tectonics. Reviews of Geophysics, 2004, v. 42, RG3002, pp. 1-35.

[7] Golitsyn G. S. Study of convection with geophysical application and analogues. L.: Gidrometeoizdat, 1981.

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sufTa wylis, H_2O, da sxvadasxva simkvrivis mqone Saqris, $C_{12}H_{22}O_{11}$, da sufris marilis, NaCl, wylis xsnarebis buStisebri duRilis TavisebureBaTa kvlevis damatebiTi eqsperimentebis Sesaxeb

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Дополнительные эксперименты по исследованию особенностей пузырькового кипения чистой воды, водных растворов сахарозы, $C_{12}H_{22}O_{11}$, и поваренной соли, NaCl, различных плотностей

Анзор Гвелесиани, Нодар Чиабришвили

Резюме

В настоящей статье рассматриваются результаты лабораторных работ, являющихся дальнейшим продолжением исследований конвективных процессов, по оригинальному лабораторному методу моделирования процесса пузырькового кипения растворов различных плотностей [1, 2]. На примере водных растворов поваренной соли и сахара тщательно

изучены особенности временного хода температуры растворов и зависимости энтропии от температуры. Показано наличие трёх характерных значений температуры, энтропии и интенсивности подаваемого тепла (T(ρ), T(t), ΔS(T) и Q′(t)) в процессе объёмного кипения изучаемых растворов, являющихся реперными точками смены режима пузырькового кипения: T (H_2O) = T($C_{12}H_{22}O_{11}$) = 40^0C, 80^0C, 100^0C and T(NaCl) = 40^0C, 80^0C, 108^0C. При этом обнаружено, что для чистой воды (ρ = 1,0 г $см^{-3}$) и водных растворов поваренной соли и сахарозы в интервалах плотностей (допустимых минимальных- максимальных значений) , соответственно: Δρ(NaCl) = (1,01-1,2) г $см^{-3}$ и Δρ($C_{12}H_{22}O_{11}$) = (1,04-1,47) г $см^{-3}$. Полученные графики зависимости между точками разрывов непрерывности второго рода – T(ρ), T(t), ΔS(T), Q′(t) – имеют универсальный характер, независимы от природы растворяемого в воде вещества и начального значения температуры раствора. Представленные экспериментальные графики (Фиг. 1-6) содержат достаточно полную информацию щоновых результатах , которые могут иметь не только прикладное значениею. Предлагаемый метод позволяет, без лишних технических затрат и времени, в первом приближении быстро и безошибочно определить основные (реперные) термодинамические характеристики изучаемых растворов.