PProblem № 17
" A Sound from water, heated up in a teapot, "
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PProblem

While heating water in a kettle, it is possible to hear a sound up to the moment of water boiling . Explore this phenomenon.

TThe list of the used literature.

1 Àñëàìàçîâ Ë.Ã. Âàðëàìîâ À.À. " Entertaining physics " 1988y., Moscow, "Science", article " While the kettle has not begun to boil "
2 Ãåãóçèí ß.Å. "Bubbles". " Entertaining physics " 1988y., Moscow, "Science", " the Partial theory of fracture of bubbles "

I have carried out a set of experiments and was convinced, that during boiling a kettle we hear a noise .

Let us try to find out the reason of this familiar noise and estimate its specific frequency.

During the process of boiling tone of sound is not the same. At first we hear hissing, then - the sound amplifies, and at last the sound of splashing water transfers in feeble singing.

I think that there are 4 channels of noise formation :

1 - During bubble separation from water surface ;
2 - When bubbles bust in water;
3 - When bubbles burst open on the surface of water;
4 -When steam passes through the spout of a kettle.

As the first reason of this noise it is possible to assume oscillations of liquid incipient with bubbles separation from the bottom and walls of the vessel. These bubbles more

often arise at nonregularities and microsplits of a surface , their sizes are of the order of 1 mm before boiling , (while boiling they grow considerably , and can reach up to 1 sm.). To estimate the frequency of incipient sound in a kettle we have to find the time of bubbles separation from the bottom. It is this time that characterizes duration of liquid push during bubble separation, and consequently the period of oscillations incipient in a fluid. Accordingly the frequency of generated sound is defined as reverse of this time:

$$\nu_1 \sim t_1^{-1}$$

There are two forces applied to a bubble when it is in rest at the bottom: up thrust force (1) and surface tention. (2) As bubble grows up thrust overcomes surface tention and bubble starts its motion up words. The mass of a bubble is not defined by the air inside but by associated mass that is equal to This the mass of liquid that really take s part in the motion. So acceleration of bubble at the initial stage of motion is: (3). The time of bubbles tearing off can be estimated now. It rises at its height during: and so the frequency of generated sound is about 100Hz. This is one order less than the tone we hear heating the kettle but far from boiling .(4)

The time of bubble separation, from the bottom can now be estimated, considering (its) motion uniformly accelerated. On height about the size it rises during (5) .

There is also the second reason, of noise incipient in a kettle with (its) heating, we followed the trace of a bubble, after (its) separation from the bottom. Leaving the hot bottom, where the steam pressure in a bubble is approximately equal to atmospheric (otherwise it could not, extend bubble gets in upper stratums of water, which are not heated enough yet .(6) Steam in the bubble cools its pressure lowers and can not any more compensate external pressure (Fig. 2). As a result, bubble bursts, or squeezes (if there are some air besides steam). So there is also a sound impulses, spread in a liquid. Simultaneous bursting of a large number of such bubbles in water, perishing in high layers, is perceived as noise. Let's estimate, (its) specific frequency.

Let's write down Newton equation , for mass of water m, flowing inside the bubble while bursting (7).

Here $S = 4\pi R^2$ -, surface area of a bubble, effected by pressure, ΔP - pressure difference at the boundary , a_r - acceleration of bubbles boundary motion to (its) centre. It Is clear, that mass involved in such process is in order of magnitude equal to the product of water density on bubble volume : m ~ 3,r3. Thus, the Newton equation , can be written as (8).

Neglecting pressure caused by tension of a curved bubble surface and small of air it contains we considered P to be- stationary, (dependent only on thermal gradient between bottom and upper stratums of water). Acceleration value

$$a_r = r''t$$

we estimated as r_0 / t_2^2, where t_2 - r time of bubbles bursting. Then in

$$r_0^2 / t_2^2 \sim P$$

Whence (9) close to Ò = 100 C, saturaed steam pressure impinges approximately on 3*10Pa with depression of temperature on 1^0 C.

Dependence of pressure of sating steams (vapours) on temperature (tabl)

Therefore for estimation it is possible to accept Δ P ~ 10 3 Pa, then the relevant time of bubble bursting will be

And frequency of noise incipient with it $\nu_2 \sim t_2^{-1} \sim 10^3$Hz.

This result is already, more similar, to the truth, than previous more.

One more reason for the benefit of such origin of noise is the fact that in accordance with water temperature , rise the frequency of high-frequency noise is gradually depressed according to (9). Immediately before boiling steam bubbles stop bursting even in high layers of water. Then the unique mechanism of sound excitation appears the above described separation of bubbles from bottom - frequency of kettle "singing" , depresses noticeably. After water boiling "voice" of a kettle can change again (especially if you take off a lid) - it is due to bubbles, bursting open already , at surface of water.

One more process related with bubble produces sound by the following channel. If you look at a surface of a boiling fluid, it is visible as large bubble, (r ~ 1 sm) with burst; on a surface steam takes off outside, and the oddments are agglomerated in "bagel" (fig.3) which rolls to a surface inputs. In the book by Ãåãóçèíà "Bubbles" the formula of duration of process of a bubble disrupture, is given (10) Fig.3 a View of a tearing bubble ñâåðõó.

Here r - size of a bubble, - coefficient of interfacial tension of water, - density of water, h - wall thickness of a bubble. In our case we should speak about fracture of half of bubble, therefore ours of t is 2 times, less than quantity from the formula Ãåãóçèíà. Bursting bubble strike, on a surface of water and cause, its oscillation with frequency (11).

for estimations we used the following values: $r = 10^{-2}$ m, $h = 10^{-7}$m $\sigma = 7 \cdot 10^{-2}$ N/m

and received $\nu_3 = 4 \cdot 10^3$ Hz

in sound formation rising bubbles of heated air also participate.

First the kettle under the closed lid, begins to boil and the stream of steam, pulled out from (its) spout informs about it. In steady, process of boiling practically all energy of heating is spent for transpiration of water. Let's consider that the spout is free and all steam leaves outside only through (it). Let as a result of energy application during t mass of water M evaporates (it) can be defined from the equation (12)

Where r - specific heat of vaporization, and P - power of a cale factor. For this time t steam should leave a kettle through a spout, otherwise it would , collect over a lid. If the area of a hole of a spout S, density of steam under a lid of a kettle (Òk), and the required velocity v we can write down the equality (12).

Density of saturated steam at T = 373 0C may be taken from the table.

Thus for rate of outflow a from a spout, we have: (12)

Substituting here P = 500W, S = 2 sm ^{2}, r = 2.26/106 äæ/kgs

We have found that V~ 1 m/s.

Thus the jet is pulled out from a spout of a kettle, which stream is defined by expression (13).

Here ρ - density of steam, v - velocity of its pulling out, S - cross-sectional area of a spout at the exit. If we have two kettles with various spouts (wide and narrow), and the stream of steam from these spouts is the same, we receive: (14)

If density of steams is identical, and it is so when, identical kettles are heated . (15).

Hence, steam from a narrow spout of pairs takes off with greater velocity. It means, that an edge of a spout they will pass by for different time: (16)

I.e. the edge of a wide spout of a kettle will be passed by for longer time. If for each time to introduce specific frequency (w4 ~ 1/ t4), we'll get (17).

Thus, the wider the spout, the lower frequency of sound will be. l produced, Hence the tone of singing, of a kettle with a wide spout, is lower. Let's estimate the sounding frequency of taking off steam. From the formula (18) it follows:

We have to note that this is the frequency of a sound of boiling water.

Sound the experience, I carried out has shown water boiling , in a kettle with a spout of diameter of 2,7 times greater, the frequency of a sound increases 7,3 times.

I have (carried out) experiment on processing the basic frequencies of a sound of a kettle. I recorded so-called "hissing with a help of a microphone ,,noise,,. I have utillized the program "Sound Forge" for it and has smoothed a sound and removed high frequencies. Then I handled this sound file by the program " COOL EDIT 96 " and received a Fourier series the computer has given out frequency 4600 hertz with precision + -10,Hz.

The experiment has shown, that my theoretical (estimations) were correct.

CConclusions

Sound produced by a kettle during boiling is superimposition of oscillations of several frequencies. Thus we conclude, that the noise of a kettle before, boiling is related with bubbles creation at the hot bottom, their separation from the bottom and collapse in upper, not heated enough stratums of water and passage of streams of a steam through a spout of a kettle.

Frequency of a sound during water boiling in kettle depends on :

- **Coefficient of interfacial tension of a fluid in a teapot;**
- **Diameter and shape of a hole of a spout of a teapot.**

TThe loudness of a sound depends only on a roughness of bottom, mass of water and power of a heating element.

First channel

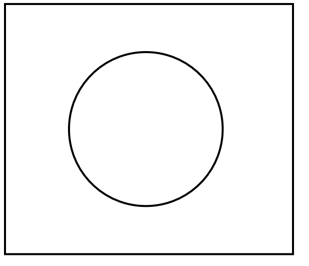
(1) $F_A = gV_п \rho_{в}$
(2) $F_H = \sigma\, l$
(3) $m = 2/3\rho_w\, \pi\, r_o^3$
(4) $a \sim F_A/m = 2g$ because $\dfrac{\rho g 4/3\pi\, r_0^3}{2/3\rho\pi\, r_0^3} = 2g$

(5) $t_1 \sim 2\, r_o/a \sim 10^{-2}$ c $\sim \sqrt[4]{\dfrac{3\sigma}{2\rho g}} \Big/ \sqrt{g}$
(6) $v \sim t_1^{-1} \sim 100$Hts

Second channel

(7) $m\, a_r = F_g = S\, \Delta P$ where $S = 4\Pi\, r^2$; $m \sim \rho_w r^3$
(8) $\rho_w r^3 = r^3 P$
$\rho_в\, r_0^2 / t_2^2 \sim P_\Delta$

(9) $t_2 \sim r_0 \sqrt{\rho w / \Delta P}$



Relation of pressure saturating pairs from temperature

Temperature ^{0}C	96,18	99,1	99,6	99,9	100	101	110,8
Pressure, кPa	88,26	98,07	100	101	101,3	105	147

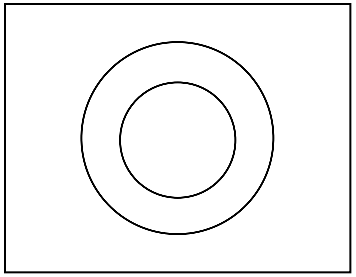
$t_2 = 10^{-3}$ c and $\nu_2 \sim t_2^{-1} \sim 10^3$ Hts.

Third channel

(10) $t_3 \sim \pi r (h\rho / 4\sigma)^{1/2}$

(11) $\nu_3 = 1/ t_3 = 2\pi r(h\rho/\sigma)^{1/2} \sim 1/2$

$\sqrt{\sigma / h\rho}$



$r = 10^{-2}$ м, $h = 10^{-7}$ м, $\sigma = 7 \cdot 10^{-2}$ Н/м

$\nu_3 = 4 \cdot 10^3$ Hz

Fours Channel

(12) $r_? M = P_? t$; $M = \rho sv_? t$

P= 500 W, $S = 2*10^{-4} m^2$, $r = 2.26/10^6$ /kg ; *V*~ 1m/c

(13) $J = Sv\rho$

(14) $j_1 = \rho v_1 s_1 = j_2 = \rho v_2 S_2$

(15) $v_1 S_1 = v_2 S_2$ or $v_1 / v_2 = S_2/S_1$

(16) $t_1 / t_2 = S_1 /S_2$ $v_4 \sim 1/ t_4$

(17) $v_1 / v_2 = S_2/S_1$

(18) $v_4 = V / g = 1$ m/c / 0,5 $/10^{-2}$ m = $2*10^2$ Hts