Hello teams of the competitor, dear judges. I am a representative of team Belarus present to your attention our decision of a problem «Bottle Battle». I shall remind the task of this problem: «Take two opened glass bottles of cola and knock one against the other. After a short while, the cola spurts out of one of the bottles. Investigate and explain the phenomenon.»

Consideration of this problem we shall begin with experiment. First we will knock bottles side by side.

After the impact we can't observe the phenomenon, which is correspond to the task of the problem. Then we shall knock bottles a bottom of one on a neck another.

As you can see, cola spurts out of the lower bottle. Now we will explain occurring with the physical point of view.

After the impact, the lower bottle gets initial speed and starts to move downwards. However, in consequence of sluggishness, movement of liquid in it can't to keep pace with the moving of the bottle. So, after the impact, between bottom of this bottle and the lower surface of the liquid, the area with the lowered pressure is formed. With reduction of pressure, solubility of gas in a liquid decreases also. Surpluses of dissolved at the bottom of the bottle gas start to liberate from cola, gathering in small bubbles. After that, under action of Archimedean force, bubbles with gas start to rise from the bottom to the surface of the liquid, where there is an intensive forming of foam, which spurts out of the bottle.

In general, foam is the system consisting of gas, liquid and surface-active substances. Foams represent as great number of gas bubbles, parted with thin liquid pellicles. It is necessary to notice, that without surface-active substances formation of foam is impossible – it collapses at once. For confirmation of it we shall lead one more similar experiment, but now instead of cola we will take clean mineral soda water, surface-active substances in which are absent.

As you were convinced, in this case foam collapses at once.

In cola molecules of surface-active substances, being adsorbed on the surface of the liquid, form a layer in which their concentration is higher, than in volume of cola. These substances reduce the superficial tension of the liquid. So, presence on the surface adsorbed layer of molecules does the liquid pellicle more steadier, and that allows to receive foam from cola. We shall notice also, that foam is formed not only on the surface of the liquid, but also in all volume of cola, since there, after the impact, presented all three necessary components: surface-active substances, bubbles with gas and the liquid.

To estimate the lowered pressure at the bottom of the bottle, we decided to lead the following experiment. We placed under a glass bell some cola and started to pump out the air from under it. At some value of pressure under the bell, begins intensive liberation of gas from cola, like it occurs in the bottle after the impact. Value of pressure which shows manometer, is approximately equal to what arises at the bottom

of the bottle after the impact. Experiment has shown, that the lowered pressure at the bottom of the bottle equally: P =

But sluggishness of the liquid is not the only reason of formation of the foam in cola. After the impact of bottles in glass of each of them there is the elastic wave extending with speed of a sound in glass. This wave results in involving in process of oscillation the bottom and the walls of the bottle. And oscillations of the bottom and walls of the vessel will lead to extension in the liquid of mechanical waves, which form areas of microcompressions and microrarefies of the medium in volume of the liquid. In this case in places of rarefies, will also begin formation of germs of bubbles, having such small sizes, that they cannot be made out to the naked eye.

The phenomenon of occurrence of the wave, also takes place at the side impact of the bottles. Now you can see video recording where formation of foam under action of the sound wave is distinctly visible. Here the bottle is located on a concrete floor, so it can't move downwards and that's why foam forms only due to occurrence of the wave.

And on the following video recording you can see formation of foam after side impact if above the surface of the liquid there is a lowered pressure.

So we deal at once with two phenomena: preliminary formation of the bubble germs under action of the sound wave and occurrence of area with the lowered pressure as a result of inertial character of movement of the liquid.

Now we'll explain, why cola spurts out of one of the bottles. The bubble with gas, formed at the bottom of the bottle, starts to rise under the action of the Archimedean force. Rising above, the bubble comes in the layers of the liquid with lower hydrostatic pressure and that's why its volume increases so increases the pushing out force of Archimed. It results in increase of speed of the emerging bubble. Speed of current of the liquid is more in those places where the section of the bottle is less, that means that in the place of narrowing of the bottle speed of the moving foam will increase, and when it will reach the neck of the bottle, foam will already have initial speed for spurting out of the bottle.

After the impact of bottles, at the bottom of the upper bottle, unlike at the bottom of the lower bottle, due to sluggishness of the liquids, the area with increased pressure is formated, so the effect considered by us here is not reached.

In that way, we have disassembled the processes occuring in system, and offered our theoretical explanation of the given phenomenon. Now we shall engage in an experimental part of the problem and define if our theory is correct.

As the part of the liquid leaves limits of the bottle, we have decided to consider dependence of the volume of the poured out cola on initial speed of the bottle, which it gets at once after the impact, and on the temperature of cola.

To define the dependence of the volume of the poured out cola on initial speed of the bottle, we shall take advantage of the following experimental installation. Here in the truncated plastic bottle (1), with the ruler (2) attached to it, the spring (3) is placed.

On the spring the researched bottle of cola (4) is put. After that on its neck strikes a blow another bottle (5). After the impact the bottle (4) comes in movement and starts to compress a spring (3). All this process is records on a videocamera (6). Then, after the viewing of record, the maximal value of compression of the spring is defined, by the fixed ruler. For carrying out of experiments the spring of known length and rigidity was used: $k=650$N/m, $l=9$sm, and also the bottle with cola which weight is equal: $m=0.9$kg.

According to the law of conservation of energy, the formula (1.4), we can find initial speed of the bottle, the formula (1.5). At known values of rigidity of the spring and weight of the bottle for the definition of its initial speed it is necessary to measure only amplitude A. To do it we have taken advantage of a videocamera and the videorecorder.

Having lead numerous experiments, we have defined dependence of the volume of the poured out cola on initial speed of the bottle. Apparently from the graph, at increase in initial speed of the bottle the volume of the poured out cola increases also, that corresponds to our theory on which the faster the bottle starts to move, the bigger area of the lowered pressure is formed. Therefore more intensive liberation of gas from cola, which subsequently forms foam on a surface, begins.

For carrying out the second series of experiments with the changing temperature of cola, we shall take advantage of the same experimental installation, but now we shall knock bottles with the same force every time. Bottles with cola we shall heat up with the water bath. After leading of a series of experiments, the following dependence diagram was found. From this graph it is possible to make a conclusion, that at increase in the temperature of cola, the volume of poured out liquid will increase too. The reason of it is that at increase in temperature solubility of gas in cola falls. Thus in bubbles which are formed in the field of the lowered pressure, gets more non-dissolved gas and they, emerging, form more foam, which spurts out of the bottle.

As in the task of the problem the form and volume of the bottles, and also the manufacturer of cola is not stipulated, we have decided to lead some more comparative experiments for various drinks. We had chosen three kinds of cola: Bela-Cola in the bottle in volume of 330ml, Cola-Light in the bottle in volume of 500ml and Coca-Cola in the bottle in volume of 250ml. As you can see, forms of all bottles are various. We had been leading the following experiment. All bottles which temperature was identical, we knocked with equal force. After that volumes of poured out cola from bottles were measured. Since in different bottles different volumes of a drink we have decided to define relative parameters of the poured out volumes, that means how many percents of all cola in the bottle were poured out. After leading of a series of experiments the following diagram was received. Apparently, the highest parameter of the ratio of the poured out after the impact cola to all volume of cola in the bottle has drink Cola-Light which we have used in all our experiments.

One more important parameter is the height of a raising of a jet of cola. We already know, that if the temperature and initial speed of the bottle is maximum, then greater volume of cola will be poured out from it. That means that under the same conditions height of a jet of cola will be maximal. Thus, after leading corresponding experiment, using videocamera and videorecorder, we found the maximal height of a jet of cola rising above the bottle. It appeared equal 27sm.

So, as we can see, all experimental findings are easily explained by our theory of fast formation of great volume of foam. It also explains the dependences received during leading of experiments.

In that way we have considered few possible impacts of the bottles, have disassembled dynamics of formation of foam, have assembled the experimental installation which has allowed us to receive graphics of dependence of the volume of the poured out cola on initial speed of the bottle and on the temperature of cola, have considered few various kinds of cola and forms of bottles, and also we have offered the theory confirmed with numerous experiments which truthfully describes the phenomenon, which interests us.

That’s all. Thanks for attention. I will be glad to answer any questions, connected to my speech.