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EXPERIMENTAL CONFIRMATION AVOGADRO'S LAW FOR THERMAL RADIATION

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ABSTRACT

Experimental study of pressure variation in metal empty sealed container in low vacuum conditions (0.1-10 mbar) for temperature range from 290 to 1490 K is presented. Three characteristic areas of pressure variation were registered: the pressure growth in accordance with Avogadro's law in the temperature range from 290 to 700-800 K, the pressure drop in the temperature range from 800 to 1300 K and again the intensive pressure increasing in the temperature range from 1300 to 1490 K. Possible causes of registered pressure variation in sealed container with increasing temperature and then cooling to its original conditions were analyzed. One of the more active causes is thermal radiation action in metal empty sealed container.

Keywords

Thermal radiation; Avogadro's law; experimental study; low vacuum conditions.

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INTRODUCTION

The present study initially was due to significant challenges of high temperature air-breathing engines design related to origin of so-called “unexpected” heat losses of working process [1-3]. These additional heat losses essentially complicate coordination of basic engine components (for turbojet - compressor, combustor and turbine, for high speed air-breathing engine - air inlet, combustor and nozzle). The first manufactured prototypes of new high temperature engines are not able to provide options that are appropriate for the initial project parameters. Therefore there is required a long technical development of new high temperature engines, resulting in significant additional time and financial costs. The present study allows along with possible fundamental scientific findings to formulate possible approaches for modern theory of heat temperature engines that implement the famous Brayton cycle [4].

We show first of all some typical experimental data for radiation power in modern aircraft gas turbine engines, which are very important for our study [5]. Radiation intensity in main combustion chambers is near $\vec{S}$=0.5-1.0 MWt/m^2 and more (for normal direction $\vec{n}$ of a considered surface). Analyzing the energy conservation law in traditional form and parameters [6-8] as

$$\frac{d}{dt}\iiint\limits_{\omega(t)} \rho\left(\frac{1}{2}q^2 + e\right)d\omega = -\iint\limits_{\gamma(t)} (p\vec{u} + \vec{S})\cdot\vec{n}d\gamma + \iiint\limits_{\omega(t)} Qd\omega,$$

we can see with the characteristic speed value /u/~1-2 m/s the additional pressure growth in a combustor inlet may be near a few atmospheres (see the first term in the right side of the above relation). Such type of radiation action should be including into account in aircraft engine design process.

An important issue is also our fundamental knowledge about the characteristics of cosmic vacuum, including in its implementation near the Earth. Naturally these characteristics are intimately linked with characteristics of the space vacuum. A fundamental aspect for us in this regard, it is carefully measured temperature value of free space T_0 = 2.73 K. Availability target temperature value of free space was theoretically predicted by G.A. Gamov in 1948 [9]. For the first time this value experimentally measured in 1956 by radio astronomic, post-graduate scientist of the Pulkovo Observatory (St. Petersburg) T.A. Shmaonov [10]. In the future there have been carefully measuring the temperature of Cosmic Microwave Background Radiation (CMBR) and shows the large scale dipole anisotropy of this radiation [11, 12].

The critical density values registration (ρ*~ 10^{-26} kg/m^3) of the Universe proposes also the non-zero density ρ_0 of space vacuum. In accordance with this item it should be given to the question of the possible non-zero value for the pressure p_0 of space vacuum. The final pressure p_0 in outer space, in one form or another, should be shown also in the Earth.

In this paper we performed pressure registration in low vacuum conditions (0.1-10 mbar) in a metal “empty” sealed container (about 0.5 liters) when it is heated in a wide range of temperatures (from 290 to 1490 K) and subsequent it’s cooling. As a main experimental result of our study there was established three specific areas of pressure variation with increasing temperature and cooling: the linear pressure growth in accordance with Avogadro’s law in temperatures range from 290 to 700-800 K, the pressure drop at temperature range from 800 to 1300 K and again the intense pressure increasing at temperature range from 1300 to 1490 K. In the reverse process of container cooling the pressure variation is also recorded and repeated. Additional evacuation of the vessel (up to 0.2 mbar) at high temperature (1200-1400 K) did not change registered pressure variation with temperature changes.

The first marked zone of the linear pressure increasing in accordance with Avogadro’s law in temperature range from 290 to 700 – 800 K seems fairly traditional. Avogadro's law establishes an experimental fact that “equal volumes of any gas at the same temperature and pressure contain equal number of molecules”. This law formulated by the Italian scientist in 1811 and in our statement will be used in the state equation form of ideal gas

$$p = nkT\,. \qquad (1)$$

Here p is the pressure (measured in Pascal’s, Pa), n is the concentration of gas molecules (1/m^3), T is the absolute temperature (K), k = 1.38 · 10^{-23} J/kg · K – Boltzmann’s constant.

For explanation of the registered pressure variation in our study (for all three marked zones) we consider thermal radiation in ideal gaseous approach (similar [6, 13]). Also we will use known experimental data for CMBR. The traditional relations

$$E = mc^2 = h\nu \approx kT, \qquad (2)$$

at the zero temperature gives quite natural zero mass particles m. However, for the final CMBR temperature T_0= 2.73 K the ratio (2) gets the non-zero particle mass [8, 14-17] for environment. Evaluation of the particle mass from (2)

$$m \approx kT/c^2 = 4.25\cdot 10^{-40}\ kg. \qquad (3)$$

A very important aspect of the issue before us is also its own thermal radiation pressure [6, 13, 18]. In our case it is determined by the ratio of (1) and particle mass (3). Experimental confirmation of the existence of such pressure and its accounting in physics and chemistry can significantly expand theoretical models of these disciplines and will provide additional characteristics of observed phenomena of nature.

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EXPERIMENTAL STUDY DESCRIPTION

In the present work there is implemented by the following methodology assessing the validity of Avogadro's law in low vacuum conditions. We will record the change in the total pressure in the metal sealed container as a result of a slow heating and cooling further in quite a wide range of temperature (from 290 to 1490 K), while the absence of adverse effects (ionization, dissociation and etc.). The thermal radiation is simulated as ideal gaseous approach. In common case we consider the total pressure p of a mixture of two gases, which is equal to the sum of the partial pressures of air p_g and heat radiation p_f. For the same temperatures of these two components one can be written

$$p = p_g + p_f = (n_g + n_f)\, kT. \qquad (4)$$

Here n_g – air concentration and n_f – photon concentration.

Set in our container the initial values of pressure p_0 in low vacuum conditions (near zero of our instrumentations, no more 0.1 mbar). In the process of heating we measure pressure and temperature very carefully and check the fairness of balance (4). By that electromagnetic properties don't include into account.

Now we present some estimation of the expected values of the thermal radiation pressure, density and concentration of photon gaseous medium at different temperatures. The published papers [14-17] received score values of pressure p_0, density ρ_0, and concentration n_0 when T_0 = 2.73 K (in a vacuum space). It amounted to $p_0 = 10^{-6}$ Pa, $\rho_0 = 1.46 \cdot 10^{-23}$ kg/m^3, $n_0 = 2.65 \cdot 10^{16}$ 1/m^3. In the Earth conditions at the temperature T = 273 K in the case of adiabatic process for photon gas with the adiabatic constant κ=4/3 we have

$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{\frac{\kappa}{\kappa-1}} = (10^2)^4 = 10^8, \qquad (5)$$

$$p = p_0 \cdot 10^8 = 10^{-6} \cdot 10^8 = 10^2 \text{ Pa (~1 mbar).}$$

From this assessment we can consider the value of initial pressure of heat radiation p_f inside the open container at T = 273 K approximately equal 1 mbar and the concentration of photon gas inside the container $n_f = p_f/kT = 2.65 \cdot 10^{22}$ 1/m^3. For comparison the concentration of air at the $p_g = 10^5$ Pa and T= 273 K is $n_g = p_g/kT = 2.65 \cdot 10^{25}$ 1/m^3.

We would like to provide the initial pressure value inside the container p_0 less than 1 mbar (preferably ~ 0.1 mbar). Thus, we study Avogadro's law justice in the low vacuum area from 10 Pa up to 1000 Pa. Our target provides in the ratio (4) the value of heat radiation pressure p_f over conventional remaining gas pressure p_g (and, accordingly, the concentration of photon gas n_f over than the air concentration n_g). Therefore, in our work one would be considered tree bands $n_f < n_g$, $n_f \sim n_g$ and more interesting for us the band $n_f > n_g$.

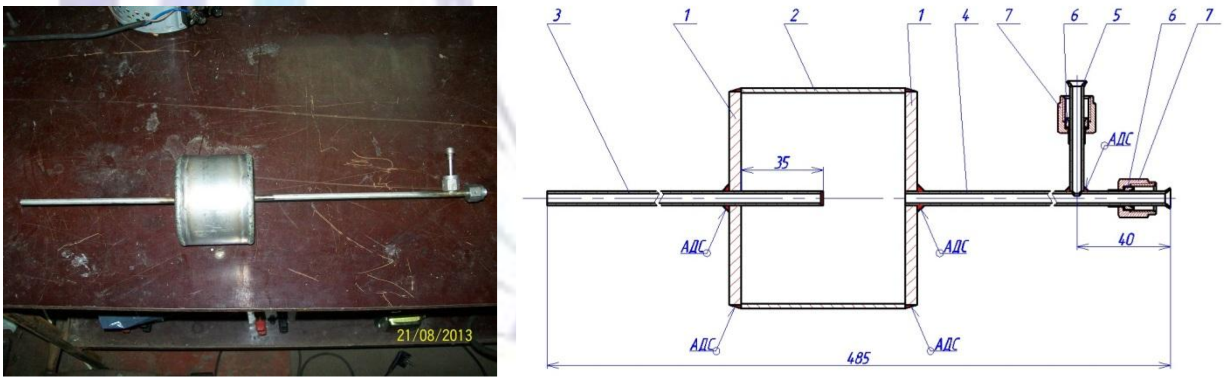

FIG. 1. Photo and vessel drawing.

The container has the form of a cylinder (Fig. 1). We manufactured two of exactly the same vessels and repeated our experiment series two times for each vessel. Lateral surfaces of the vessels (2) were made from metal alloy VG-98 with 2 mm thick, end surfaces (1) from the VG-98 with thickness 5 mm. Through the left end surface of the vessel there were tubes with internal thermocouples (3), through the right end surface there were selection of static pressure tubes (4), combined through the tee with pipe for air sampling (5). Ratio of "cold" and "hot" volumes of vessels stood at 0.4%. In the process of experiment the temperature was measured also on the outer wall of the models in the 5 points (3 points on the cylindrical surface and one at each end), the ambient temperature inside the model and its static pressure (one or two pressure sensors). For temperature measurement used the standard XA thermoelectric converters with accuracy in the range 0.75%. The diameter of the hot junction amounted to 0.6 mm. The pressure was measured by sensors VCC200-MA4 with range 0.1-200 mbar absolute pressure and with an accuracy of 0.25% of the maximum measured value. Ceramic term stable vacuum gauge sensor ensures stable vacuum measurement of high repeatability of the results. Registration of signals with the measurement tools were LTR firm's modular measuring system "L-card". Error of measurement modules LTR is 0.0025%. The model was reliable heat is isolated from the environment by the special basaltic cord. Our experimental study was repeated using each from two manufactured vessels.

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With help vacuum pump there was installed the initial pressure p_0 inside the vessel. More important for our study there was a low vacuum conditions (less than 0.1 mbar). Typical heating time for model was 60-120 min. and more (in some cases vessel stays long time at constant high temperature, ~1300 K), time cooling model was about 60 minutes, time to cool down completely was about 180 minutes.

EXPERIMENTAL RESULTS

The first series of experiments was performed to test obtained experimental results when $n_g >> n_f$. The initial pressure p_0 consistently was selected from one bar and had values 1.0; 0.4; 0.2; 0.1; 0.05 bars (consistently decreasing from 10^5 Pa up to $5{\cdot}10^3$ Pa). Here all results corresponded to linear pressure growth and drop with temperature variations when heating and cooling vessels. Some deviation from the linear relationship was observed at temperatures over 1000 K. This effect was associated with partial absorption (adsorption) metal surface molecules of oxygen and nitrogen (in particular, nitriding and oxidation of the internal surface of the receptacle).

A second series of experiments were performed for the initial pressures p_0 = 30 mbar and p_0 = 3 mbar (here also $n_g > n_f$). We could demonstrate significant impact effects of adsorption of air gaseous environment inside the metal container when heated and prolonged maintenance at a constant high temperature (1300 K). These results are shown in Fig. 2, 3 and 4 respectively for the p_0 =30 mbar and p_0 = 3 mbar. Using adsorption effect we can significantly reduce concentration of air gaseous environment in the vessels and realize the correlation $n_f \sim n_g$.

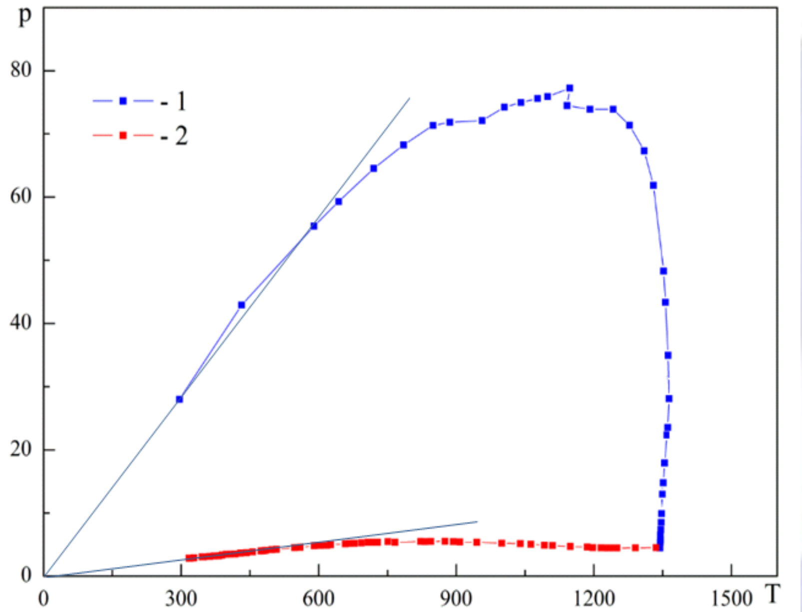

FIG. 2. Pressure (p mbar) variation on temperature for p_0=*30 mbar* with constant of high temperature zone (~1300 K); 1 – heating and the zone with T~1300 K, 2 – cooling vessel.

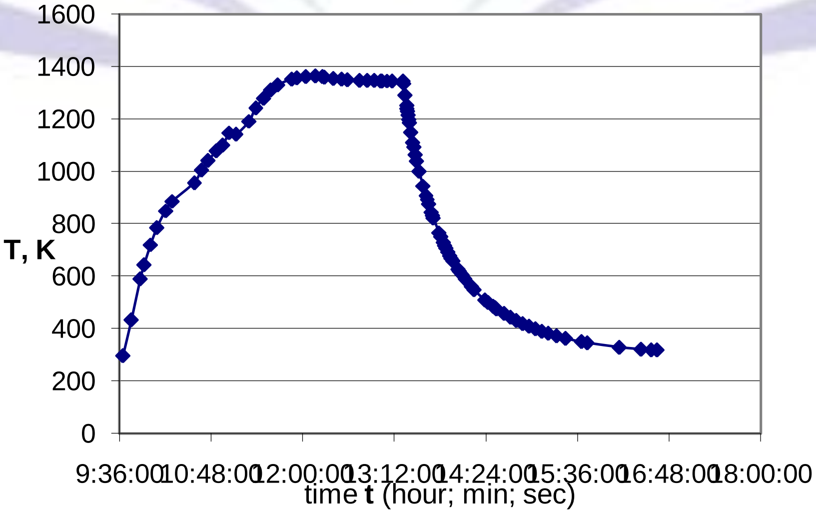

FIG. 3. Temperature variation on time for p_0=*30 mbar* with constant high temperature zone (~1300 K).

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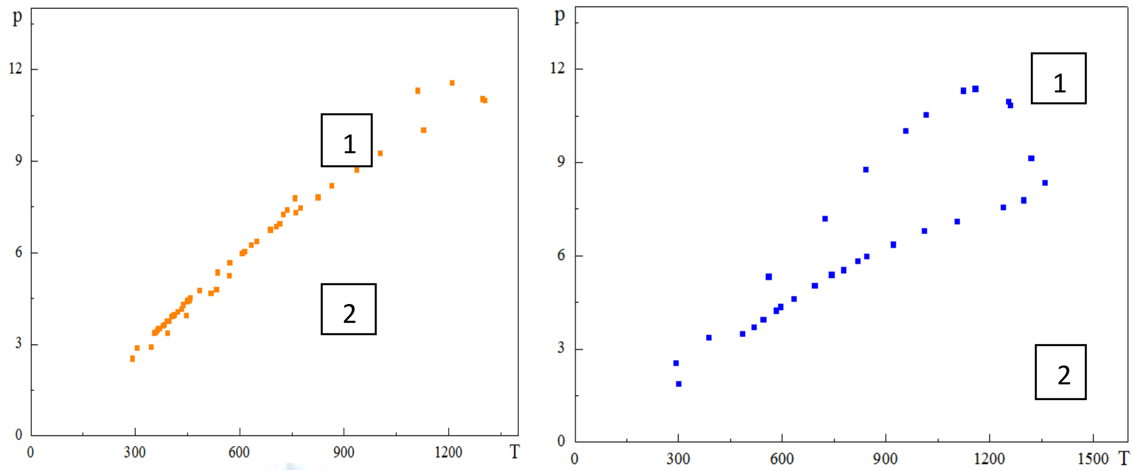

FIG. 4. Pressure variations on temperature for p_0 = 3 mbar in two consequent experiments for demonstration of air adsorption effects (1 – heating; 2 – cooling).

In the third experimental series we would like to obtain concentration n_g (normal baryonic gas) no more than 10% and less of the total concentration of the left in the vessel environment. Additionally a few times we run vacuum pumping the vessel in the hot conditions (with temperature T=1300-1400 K) and getting to lower pressure (from 2-3 mbar to 0.5 mbar). Here we had “empty” vessels (with $n_f >> n_g$). The third characteristic plots (Fig.5, 6 and 7) show these typical resuts and, in paricular, the intensive increase of intracellular environment inside the vessel (if T > 1300 K). When cooling of vessels once again we recorded the sequence of changing pressure and actual recurrence pattern change, which recorded during heating.

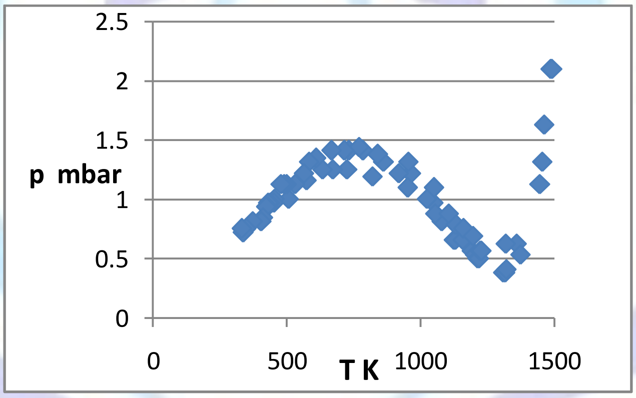

FIG. 5. Pressure variations on temperature for p_0 = 0.6 mbar (for “empty” vessels with $n_f >> n_g$).

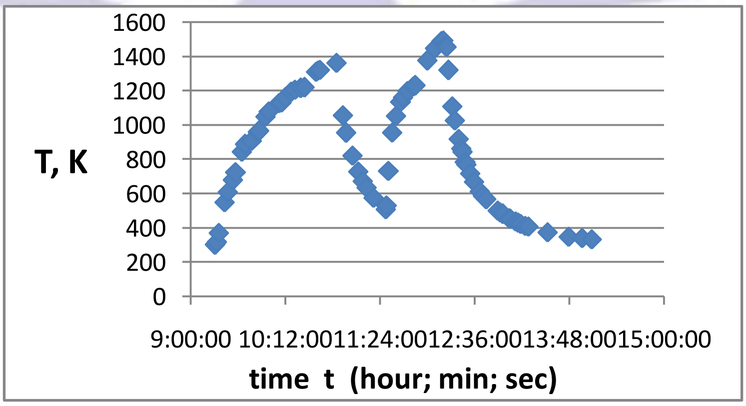

FIG. 6. Temperature variation in time for p_0 = 0.6 mbar (with two heating zones).

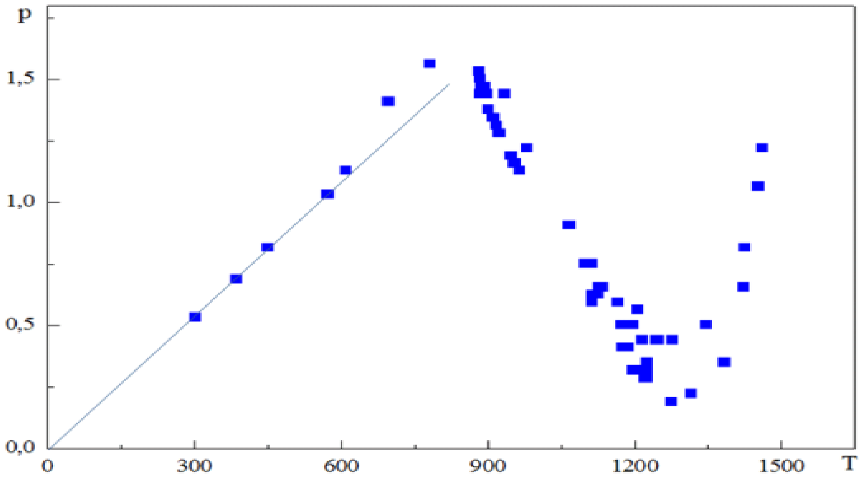

FIG. 7. Pressure variations on temperature for p_0 = 0.5 mbar (for “empty” vessels with $n_f >> n_g$).

CONCLUSION REMARKS

The main purpose of this study was a demonstration of Avogadro’s law justice in low vacuum conditions for gaseous environment, enclosed in a metal “empty” sealed container. A key issue was to determine the temperature range at which remains Avogadro’s law justice. The gaseous two phase environment was regarded as air and heat radiation in the approximation of a perfect gas. The main result of experimental studies has the demonstration of Avogadro’s law justice in wide temperature range from 290 K to about 700-800 K (throughout wide range of initial pressure p_0, from 0.5 mbar or less up to 10 mbar and above). We have registered the pressure drop in the temperature range from 800 to 1300 K and again the intensive pressure increasing in the temperature range from 1300 to 1490 K.

An attempt was made to reduce the impact of air concentration (the usual gaseous matter) up to zero (realization of “empty” vessel), using additional vacuum pumping also in high temperature region. In this case the results of our experiments have confirmed Avogadro’s law for thermal radiation in the same range of temperatures (from 290 to 700-800 K). With further heating of the vessel there is intensive environment reducing the concentration, that can be attributed to adsorption of photon medium by metal walls of the vessel. The phenomenon of adsorption in case of radiation has a place for photon radiation.

The final third of the registered ranges with growth concentration (when T > 1300) may partially be explained by the "evaporation" substances from the surface of metal walls (or polarized spaces of atoms and molecules [17.18]).

It should be specially emphasize the important effect. Interaction of air components with the walls of the vessels in temperatures ranging from 800 to 1300 differs from heat radiation effects. In cooling processes (when $n_g > n_f$) are registered lower values of pressure. At the same time, for cooling processes (when $n_g < n_f$) the observed pressure values are restored. Identified in the series of experiments the effect of heat radiation adsorption by metal surfaces of the vessels during heating and cooling in the temperature range from 800 to 1300 K (with corresponding pressure variations) can have a fundamental principle. We have demonstrated a simple enough experimental study for registration thermal radiation in metal vessel (experiments on “Little Photon Collider”). Such experimental study can be easily repeated in each physical laboratory.

The authors are planning to perform additional experiments, using not only the receptacle made of metal alloy, but also similar vessels made from other materials (ceramics, based on organic compounds, etc.).

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