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RESEARCH ARTICLE OPEN ACCESS

OXYGEN ENERGETICS: GENERATING ENERGY FROM HIGH PRESSURE OXYGEN USING AN ELECTRIC FIELD

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ABSTRACT

The aim of this article is to study the mechanism of explosions in high-pressure oxygen cylinders, first to prevent explosions, and then to try to control this process in order to obtain an environmentally safe source of alternative energy. Using the numerical value approach method based on the Hamiltonian system of the kinetic model of complex reactions, the critical ignition state for the reacting gases was determined. As a result of numerical calculations, it was shown that for a mixture of atomic and molecular oxygen, at a pressure of 150 atm, the presence of a critical state in the system depends on the atomic oxygen concentration.Methods for utilizing the resulting thermal energy are proposed.

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INTRODUCTION

In connection with the inexhaustibility of oil and gas reserves, an urgent problem is to search for synthetic energy resources. Synthetic energy resources should be considered those that, first of all, exist in large quantities, are renewable and have a minimal or completely harmless effect on the environment. Such synthetic energy sources are, for example, some metals and non-metals (Mg, Al, S, Si, P, N, etc.), the reserves of which and the positive energy balance during their oxidation-reduction, can be considered inexhaustible for such energy sources. From this point of view, the use of internal energy of aqueous solutions is also an important and promising area (Martoyan G.A., Karamyan G.G., Barseghyan A.R., 2006, Martoyan G.A., Karamyan G.G., Barseghyan A.R., 2005). From time to time, there are reports of explosions of high-pressure oxygen cylinders and the tragedies accompanied by human casualties and destruction of buildings, that have arisen from them, mainly due to the penetration of micrograms of oil into the cylinder through the valve. It is known that the interaction of oil and oxygen is a strong exothermic oxidation process, which leads to ignition and explosion. When oil comes into contact with oxygen, especially under high pressure or high temperature, an explosive mixture is formed. The mechanism involves chain radical oxidation. Oxygen reacts with oil to form unstable peroxide compounds, which then decompose to release energy and new radicals, supporting the continuation of the chain reaction. However, in the case of explosions of oxygen cylinders, this explanation seems implausible, since insignificant amounts of oil act only as catalysts, while the chain extensions must be derived from oxygen. In other words, it is not the oil that burns during the reaction, but the oxygen**.** What is happening, is it possible to control this process, first of all, to exclude such explosions, and then to find out the possibility and conditions for using the huge energy flows that are released? To answer these questions, it is first necessary to find out by what mechanism the process proceeds. It is only known that during loading, unloading, transportation, storage and use of oxygen cylinders, it is necessary to exclude their hitting each other, falling, damaging and contaminating the cylinders with lubricants. The cylinders must be protected from precipitation, sunlight and other sources of heat. And how to make the energy of high-pressure oxygen released in the form of an explosion controllable, obtaining in this case new reserves of synthetic energy, to answer this question, one must first have an idea of the explosion mechanism, to find out the boundary conditions for the explosion. Then, effective and reliable control parameters of the control process must be proposed. This work is devoted to clarifying these and similar problems.

Problem Statement and theoretical Considerations: As mentioned, many cases that have occurred in practice indicate that insignificant amounts of oil particles have caused explosions of oxygen cylinders, where the pressure required for their rupture is more than 410 Atm.

The question arises: do only oil particles cause an explosion? Let's try to find out, and if there are no other foreign impurities in oxygen under high pressure, is an explosion possible?

Cylinder rupture before explosion

Cylinder rupture after explosion

First, in order to cause an explosion, small particles of oil must generate chain-continuing particles, which, as a result of a branched chain process, will ensure the integrity of the reaction throughout the entire volume. Atomic oxygen is obviously one of them. Ignoring the mechanism by which atomic oxygen is produced after the penetration of oil or other organic lubricant particles into a high-pressure oxygen system, let us immediately calculate how much atomic oxygen can cause critical phenomenas in the system and whether there is a positive balance between the energy released during an explosion and the energy costs of obtaining atomic oxygen necessary for the explosion.As an object of a numerical experiment, we will take pure oxygen 150 Atm. The initial task should be to determine the initial boundary concentration of atomic oxygen, in which case the system will appear in a state of criticality, that is, a sharp transition from the slow regime of the interacting system,a fast regime of interaction will occur in the system. The required amount of atomic oxygen in the system, at a fixed initial oxygen pressure, will be provided by generating a flow of free electrons under the influence of an electric field. At high pressure conditions of 150 Atm, the electron concentration can reach 10^{17} electrons per cm^3 using an electric field (Phelps A. V., 1985, Petrov A.E., Titov V.A., Smirnov S.A, 2013). If we choose the electron concentration in the system as the controlling parameter, then by controlling it using the electric field, we will also control the atomic oxygen concentration in the system. Therefore, it makes sense to determine the criticality state of the system depending on the initial electron concentration. Having determined the occurrence of the criticality state depending on the electron concentration, then by solving the kinetic equations we will also determine the limiting values of atomic oxygen for the critical state of the system. Thus, let us calculate the initial electron concentration, which will cause a criticality state in a 50-liter oxygen cylinder at a pressure of 150 Atm.

Defining the critical state of a system: Theoretically, a process description can be made if first the functional describing the phenomenon is given (it should be some measured macroparameter), and then the kinetic model of the system, which actually fixes the mutual relationships existing in the system between concentration changes and other kinetic parameters. As a target functional, we have previously chosen the pressure change in the system, and as a criticality condition, the minimality of these changes in the process, from which the quantitative boundary values of the initial concentrations are determined. The criticality conditions in interacting gases with L-components, according to the *Value* theory(Tavadyan L.A., Martoyan G.A.,2014,Tavadyan L.A., Martoyan G.A., 2021), are defined as the minimum of the resulting pressure change integral:

$$J=\int_0^t \frac{dP}{dt}dt \longrightarrow \min \qquad (1)$$

Accordingly, the Hamiltonian function for the system will have the following form:

$$H=\psi_o \cdot dP/dt + \psi_T \cdot dT/dt + \Sigma\psi_i \cdot f_i \qquad (2)$$

where,ψ_o, ψ_i, ψ_T are the adjoint functions of the corresponding components (respectively for P-pressure, n_i-the concentrations of the i-components in the gas, and T-teperature) that are determined from the following equations:

$$d\psi_i/dt = -\partial H/\partial n_i \text{ , } d\psi_T/dt = -\partial H/\partial T,\ \psi_o = -1 \qquad (3)$$

$$P=k \cdot N \cdot T \qquad \text{where } N= \Sigma n_i$$

$$f_i= dn_i/dt$$

$$dP/dt = T \cdot dN/dt + N \cdot dT/dt \qquad (4)$$

$$dT/dt = Q^+ - Q^-$$

$$dN/dt = \Sigma f_i$$

$$d\psi_T/dt = -\partial H/\partial T \qquad (5)$$

The condition for the minimum of the functional in (1) takes the following form:

$$\sup(H) = 0 \qquad (6)$$

$$\partial H/\partial U = 0 \qquad (7)$$

In the above, P is the pressure in the system, T is the temperature, n_i are the concentrations of the i-components in the gas, and k is the Boltzmann constant.

Whereas, the governing parameter U can be: P, n_i, T, a kinetic parameter, an inhibitor or the concentration of a catalyst, etc.

The criticality condition according to the U-governing variable parameter is the extremum of P, which is expressed by condition (6). In the case of such an approach, the question of whether the explosion, that is, the sharp increase in pressure in the system, is due to a thermal process or a rapid increase in particle concentrations, is already convincingly revealed, especially in the presence of well-developed numerical methods. There is no longer any need to separate these in order to obtain a simplified model; accordingly, it is permanently accepted that the explosion has a chain-thermal nature. It is worth noting that from the above criticality condition, in a particular case, the known 1-3 ignition limits for the hydrogen-oxygen system, which is considered the standard, are obtained; and moreover, a previously undiscovered 4th ignition limit is also obtained (Tavadyan L.A., Martoyan G.A., 2021). and the mechanism of its occurrence is thus explained. It is expedient to describe the criticality conditions from the point of view of energetics. Taking into account that in gases at constant volume the gas pressure is linearly related to the internal energy, instead of changes in pressure in the criticality condition (6), we consider changes in internal energy. In this case, the criticality criteria will not change from this, but we will have the opportunity to have not only the equations of motion of the system, but also, by evaluating the role of individual energies in the functional, to track and evaluate the contributions of the energies of individual forms of motion to the establishment of the critical state.

In the latter case, the Hamiltonian expression obtains the following form:

$$H=-\psi_o\cdot dU/dt + \psi_T\cdot dT/dt + \Sigma\psi_i\cdot f_i + PdV/dt + \Sigma G_i\cdot F_i \qquad (8)$$

$$dU= \psi_T\cdot dT + \Sigma\psi_i\cdot dn_i + PdV \qquad (9)$$

Here, the $\psi_i$adjoint-value functions take the meaning of the chemical potential of the i-component, and the added $\Sigma G_i\cdot F_i$term is introduced to emphasize that there are still unexplored and undiscovered forms of motion that can have a significant impact on the process. It is interesting to compare expression (9) with the Gibbs equation $dU=TdS - PdV+ \sum\mu_i dN_i$. As we see, the Gibbs equation is a special case of (9) and is valid only for stationary equilibrium states of a macroscopic system. The $\psi_i$adjoint-value functions coincide in their meaning with the chemical potentials of the i-component, the $\psi_T\cdot dT$ term replaces the bound energy TdS, and ψ_T is interpreted as the value of the change in internal energy per unit temperature change. Such a representation is convenient for describing processes in non-stationary and non-equilibrium systems, in contrast to the formalization of bound energy by entropy, where entropy is valid only for estimating stable equilibrium states of a macroscopic system. At the same time, many authors use entropy to study non-stationary and non-equilibrium systems, which is incorrect. As is generally accepted, bound energy is that part of the internal energy that is not converted into work in stationary equilibrium states of the system. As can be seen from (9), such a restriction does not exist for the $\psi_T\cdot dT$ term.

Management of chemical processes with evaluation of motion patterns in specific discussed problems

The management of chemical processes is one of the most urgent problems encountered in practice, which is also directly related to the activities of predicting criticality phenomena in complex chemical systems and their effective use. As is known, critical phenomena manifest themselves in the form of qualitatively abrupt changes in the system, in the event of insignificant changes in the kinetic parameters, the initial concentrations of interacting gases, or their ratios, as well as in the external parameters (P, T, reactor material, dimensions, geometric shape, etc.). These changes can be manifested both by a sharp transition from a slow regime to a fast regime of interaction, and by a very slow change in the rate of change during the initial period of this transition. In the latter case, it is extremely difficult to experimentally determine the criticality limit of the process, since abrupt changes in the system may occur after months or years. In the case of a thermal explosion, the increase in the reaction rate is entirely due to the temperature dependence of these rates, and in the case of a concentration explosion, the main factor is the steady increase in the number of particles participating in the system, due to the chain nature of the interactions between them. A thermal explosion is observed in both chain-branched, degenerate branching, and non-branching processes. The explosion is mainly expressed in a violation of the balance of the amount of heat generated and the amount of heat removed in favor of the generated one. The evaluation of motion forms becomes meaningful when the form of the objective functional is known, after which it is already possible to reveal the value of each motion form in the behavior of this functional. The application of the proposed extremum principle for specific cases allows us to evaluate each motion form in the objective functional, thereby to some extent orienting the course of the investigation. Each motion has an evolutionary development and it is not correct to determine the contributions of motion forms to the energy balance by the initial parameters describing the motion. It is necessary to find quantities in the problem formulation that are a necessary condition of development, and only under this condition to value the forms of motion. In the case when it is important to reveal the natural course of actions caused by energy changes in the process, we will use equation (2) of the energy balance of energodynamics, and accept the extremum Hamiltonian condition as the necessary condition. And when it is necessary to manage the process, by the evaluation of the contributions of motion forms in the specific problem under consideration, it is carriedout based on the extremum requirement of the corresponding target process (Pontryagin L. S., Boltyanski V. G., Gamkrelidze R.V.,1964). In this case, if we consider the objective functional of the process as $F[f_1(t), f_2(t), \ldots f_m(t)]$, then

$$H = f_0 + \sum_{i=1}^{m} \psi_i \cdot f_i(x, \dot{x}, t) \qquad (10)$$

where,

$$\psi_i(t) = \frac{\partial F[f_1(t), f_2(t), \ldots . f_m(t)]}{\partial f_i(t)} \backslash_{f_0 = f_i(t_0)} \qquad i = 1,2, \ldots . m \qquad (11)$$

And

$$f_0(t) = \frac{dF[f_1(t), f_2(t), \ldots . f_m(t)]}{dt} \qquad (12)$$

Expression (10) is the definition of the value of the charge of the i-th movement in the objective functional, as the response of the functional to a small change in the velocity of that charge at the initial moment $t_0$of the functional time t. It is also important to clarify the contribution of each motion form to the objective functional. As follows from the adopted form of the Hamiltonian, the following can be taken as the contributions of individual motion forms:

$$B_i(t) = \psi_i(t) \times f_i(t) \qquad i = 1,2, \ldots, m \qquad (13)$$

Such an approach has previously been used to study kinetic models of chemically interacting systems (Howatson, A.M., 1976).

Calculation of the criticality state of the system for a mixture of oxygen and atomic oxygen interacting: The kinetic model of oxygen with atomic oxygen presented in Table 1 was chosen as the subject of study. For calculations, the values of the heat transfer coefficient α and the heat capacity coefficient c_v under non-isothermal conditions are equal to $2.7\cdot10^{-6}$ $kJ\cdot cm^{-2}\cdot K^{-1}\cdot s^{-1}$ and 0.0254 $kJ\cdot(kg\cdot K)^{-1}$ at T=760K, respectively (Tavadyan L.A., Martoyan G.A., 2021). Heterogeneous phenomena associated with the cylinder walls under high pressure conditions were neglected.

Chemical mechanism: The computer program "VALKIN" was used for numerical calculations of critical conditions. In this program, the system of differential equations was numerically integrated using the modified Runge-Kutta method, Row-4a [5]. As a criterion for the critical state of the reaction, the condition of minimization of the objective functional (1) for the case of active particles was chosen. According to (1), the initial values of the concentrations adopted for numerical integration are as follows: [O]=0, $[O_2]=3.6E+21/cm^3$ and $[O_3]=0$, while the initial values of the adjoint functions are: for the [O] active particles $Y_0 = 1$, for $[O_2]$ $Y_1 = 0$and for the $[O_3]$particles $Y_2 = 0$.

Table 1. Kinetic mechanism of the interaction of atomic oxygen withdioxygen

№	*Reaction*	*A* cm^3/s particles	*n*	E_a	DH_{3002} kJ/mol
1	$O+O_2=O_3$	$1.63\cdot10^{-16}$	0.0	0.0	-107.0
2	$O+O_3=O_2 + O_2$	$4.66\cdot10^{-16}$	0.0	0.0	-391.0
3	$O_3 + O_2=O+O_2+O_2$	$2.56\cdot10^{-12}$	0.0	0.0	107.0
4	$e+O_2=O+O + e$	$4.80\cdot10^{-09}$	0.0	0.0	246.0
5	$O+O +O_2=O_2 + O_2$	$4.20\cdot10^{-33}$	0.0	0.0	-492.0
6	$O+O_2+O_2= O_3 + O_2$	$7.10\cdot10^{-34}$	0.0	0.0	-107.0

Note: The reaction rate constants are given by the Arrhenius equation: $k(T)=A\cdot T^B\cdot exp(E_a/RT)$, where A is the pre-exponential factor, E_a is the activation energy, T is the temperature in Kelvin, B is the temperature's dependence index, R is the universal gas constant. DH300.2 (kJ/mole) is the thermal effect of a single phase at T = 300.2-K.

Figures 1-and-2 below show the pressure and temperature changes calculated from the criticality principle as a function of the initial electron concentrations, which are kept constant for t=0.03 s.

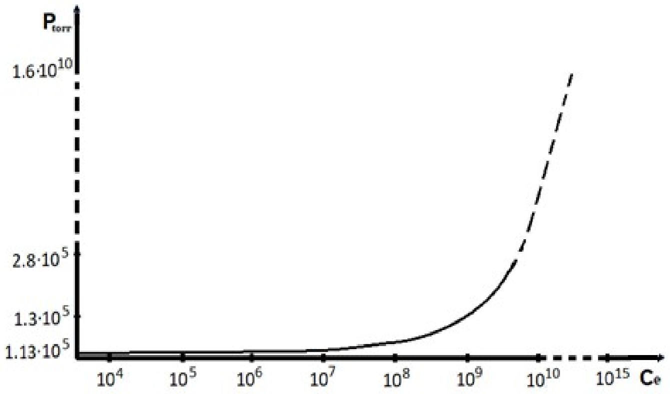

Fig. 1. The calculated change in pressure P (Torr), in the oxygen at 150 Atm,as a function of the initial electron concentration C_e (number of electrons/cm^3), at time t=0.03 s.

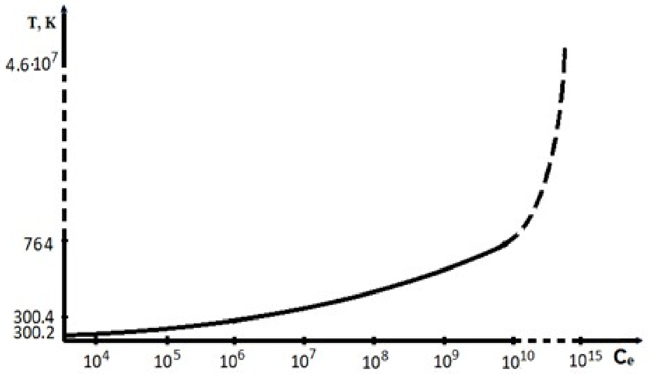

Fig. 2. The calculated temperature T (^oK) changes, in the oxygen at 150 Atm, as a function of the initial electron concentration C_e (number of electrons/cm^3), at time t = 0.03 s

Kinetic calculation: Let us perform kinetic calculations according to the mechanism given in Table 1, to determine the correspondence of the changes in the behavior of the parameters characterizing the system,for the definition of criticality of the obtained ignition limit. When 10^6 electrons per cm^3 are introduced into the system under the same conditions, a thermal explosion also occurs, but the electron flow in this case must be kept constant for a longer period of time. Fig. 3 shows the behavior of the kinetic curves at a pressure of 150-Atm and a temperature of 300.2-^{o}K when 10^{10} electrons per cm^3 are introduced into the system. The calculation shows that small amounts of atomic oxygen, which are excited by electrons, can cause huge changes in the system by generating thermal energy.

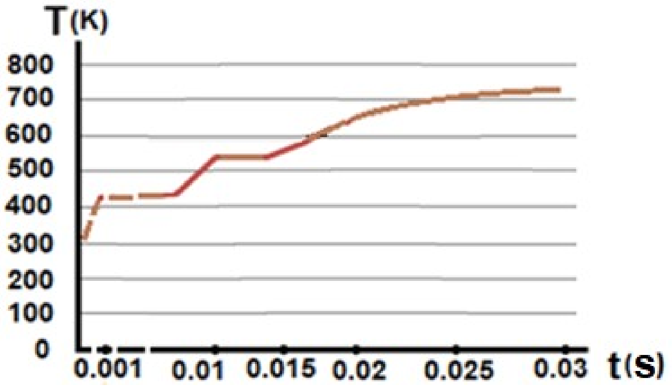

Fig. 3. Temperature change curve (e=10^{10}/cm^3, $[O]_0$=0, $[O_2]_0$=3.6E+21/cm^3,$[O_3]_0$=0, $\alpha = 2.7 \cdot 10^{-6}$kJ·cm^{-2}·K^{-1}·s^{-1})

The insignificant changes in the oxygen concentration (Fig. 4) suggest that the increase in pressure is mainly due to the increase in temperature, that is, the process proceeds in a thermal mode. The calculation also shows that only 0.8% of the oxygen is consumed. This is the case when the process proceeds by a chain mechanism, and the pressure in the system increases mainly due to the increase in temperature.

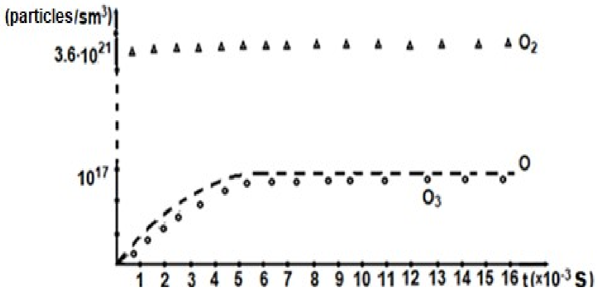

Fig. 4. Kinetic curves for the speciesO, O_2 and O_3, (for e=10^{10}/cm^3, $[O]_0$=0, $[O_3]_0$=0)

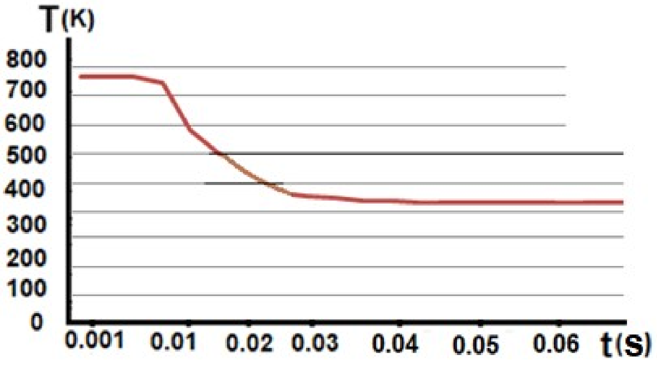

Fig. 5. Temperature change curve when the electron flow is stopped and active conditions for heat extraction are created (for e=0, $[O]_0$=1.0E+17 cm^{-3}, $[O_2]_0$=3.6E+21 cm^{-3},$[O_3]_0$=1.0E+17 cm^{-3}, and$\alpha \cdot S/V \approx 0.07$kJ·cm^{-3}·K^{-1}·s^{-1}), where S and V are the surface area and volume of the heat exchanger, respectively

Energy balance: As follows from the results presented in Fig. 3, the oxygen concentration undergoes insignificant changes in the process, which means that in case of adding new atomic oxygen doses, the energy production will be continuous. Now letus find out what energy costs will be incurred to make this process continuous, and whether shall we have a positive energy balance?

Let us make approximate estimates to determine what kind of positive balance we can expect to have in the future. The concentration of electrons introduced into the system serves as a lever for controlling the atomic oxygen doses. We note immediately that many important factors necessary for the generation of electrons, such as those related to heating, the size of the electrodes, the materials and the distances between them, as well as other near-electrode processes, for now will not be taken into account in these estimates. First, we estimate the amount of energy that will provide the required concentration of atomic oxygen to bring the system to the supercritical regime. As shown in Fig. 1, it can be seen that to obtain the required amount and more atomic oxygen, it is enough to obtain 10^{10} electrons/cm^3. Let us now calculate the energy expenditure to obtain 10^{10}/cm^3 electrons: the energy required to obtain one electron by the first ionization of O_2 is 12.07 eV, therefore the total energy required to produce these electrons will be:

E_{tot} =12.07 eV $\cdot 10^{10}$ or $E_{tot} \approx 1.934 \times 10^{-8}$ J.

Now, we estimate what amount of energy will be obtained as a result of the interaction of 10^{10} electrons and oxygen in a volume of 1 cm^{3}atthe pressure of 150 Atm.

Figures 1-4 show a slight increase in particles in the system and the temperature, and therefore the internal energy; it has increased by 2.55 times. Let us estimate the energy expenditure that will be spent in 1 cm^3, to raise oxygen at a pressure of 150 Atm from 300-K to 736-K according to $E=m\cdot c_V\cdot(T_2-T_1)$. Under these conditions, $c_V\approx 10.1$ J/(g·K), and the calculated value of the mass is $m\approx 2.57\times 10^{-4}$g, therefore we will obtain $E\approx$ 1.31 J/cm^3. Let us estimate the energy expenditure necessary to maintain the electron density of 10^{10} electrons/cm^3 constant for 0.03 s. To ensure the flow of electrons in the electrode space 1-cm apart in oxygen, at the pressure of 150 Atm, we first determine the minimum electric voltage at which an electric discharge will occur between the electrodes. With these parameters, using Paschen's law [9], we obtain V=9'200 Volts for the voltage. Whereby, Electron flow rate:$N/t=10^{10}$ e /0.03 s $\approx 3.33\cdot 10^{11}$ e/s

Current: $I=e\cdot N/t$ where $e=1.602\cdot 10^{-19}$ C: $I=1.602\times 10^{-19}$ C/e$\cdot 3.33\cdot 10^{11}$e/s $\approx 5.34\cdot 10^{-8}$ A

Hence, the energy expenditure is:$E=9200$ V $\cdot(5.34\cdot 10^{-8}$ A$)\cdot 0.03$ s $\approx 1.5\cdot 10^{-5}$J

So, it turns out that by using the internal energy of the system in the process and spending only $\approx 1.5\cdot 10^{-5}$J energy, an additional energy of 1.31 Joules can be obtained, per cm^3.

As we can see, the estimates made are very encouraging, so much so that it is advisable to perform more detailed modeling and software calculations in the future.

If we have a 50-liter (L) cylinder of oxygen under pressure of 150 atm, then by approximate estimates the additional energy per second will be: 1.31 J/cm^3 · 1000 cm^3/L · 50 L = 65.5 kJ/s, or equivalently, we will have a power source with the capacity of 65.5 kW.

The question arises,from where is coming this additional energy? If more energy is spent on the process in a natural way, than the energy expenditure of artificially bringing it to its initial state, then this is often interpreted as a violation of the conservation of energy law, without taking into account that energy must be conserved if the energy expenditure in the process and on recovery is carried out by the same mechanisms. For example, the same amount of thermal energy is spent for the thermal decomposition of an oxygen molecule that is also necessary for its subsequent recovery. That is, no additional energy is generated during the thermal dissociation of the oxygen molecule and its subsequent thermal synthesis. And, if the oxygen molecule is mechanically broken, then 2.56-eV of mechanical energy is sufficientto do so. In this case, the valence electrons of the oxygen atoms are free, devoid of the energy corresponding to such a state, since the process of absorption of 2.56-eV by each of them will be absent. However, the electrons cannot remain in this state: they must immediately replenish the energy that they did not receive during the mechanical rupture of the bond between them. From where will they get this energy? There is only one source: the environment, that is, the physical vacuum filled with ether. The latter immediately converts the ether into 2.56-eV of energy. The next stage is the connection of two oxygen atoms, the valence electrons of which have replenished their energy reserves with ether. This process is accompanied by the emission of photons with an energy of 2.56-eV by both electrons. Thus, the energy of the absorbed ether is converted into thermal energy of photons. Having spent 2.56-eV of mechanical energy on the decomposition of an oxygen molecule, we obtain twice as much energy (2.56 × 2 = 5.13 eV) during the subsequent synthesis of this molecule. The additional energy is equal to 2.56 eV (Kanarev F. M. 2003).

Despite this assertion about the physical vacuum, let's try to understand how different forms of motion can contribute to the generation of additional energy by "circumventing" the energy conservation law, or in this case, what should be understood by the term physical vacuum. The mutual relationships between the known forms of motion are well described in energetics. However, there is the same problem here as in the case of the energy conservation law. The problem is that we do not fully master the forms of motion, just as we do not master all forms and manifestations of energy. Thus, only 5% of energy is still available to us, therefore, as many justify in such cases, the additional energy is obtained from the vacuum, so by the term vacuum we should conditionally understand the approximately 95% of energy quantities that have not yet been discovered (i.e. dark matter and dark energy.) As mentioned from an energetic point of view, the path of the reaction is very important, on the other hand, it should be understood as the control of the reaction process in order to obtain maximum results. Control will represent both the choice of motion modes and the ability to obtain maximum additional energy with minimal energy impact on them. Calculations show that the additional energy depends on the rate of heat extraction, the concentration of electrons, the moment of interruption of the electron flow, and the time interval for the re-introduction. For example, in Fig. 6, with successful changes in the intervals τ_1 and τ_2, additional energy can be obtained, otherwise, energy is wasted.

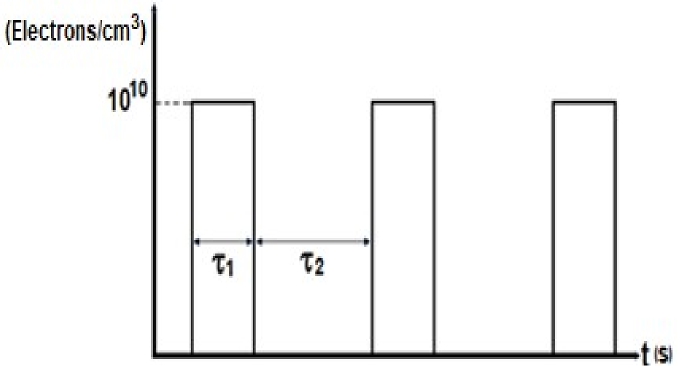

Fig. 6. The introduction of electrons into the system in fractions. The period $\tau_1$corresponds to the introduction of electrons and energy generation, τ_2 corresponds to the extraction of energy by a heat exchanger

How to use the obtained thermal energy?: From the above rough estimates, it was found that under the above conditions, an additional energy of about 65.5-kW can be obtained from a 50-liter cylinder of oxygen under a pressure of 150-Atm. As can be seen from the calculations, when atomic oxygen and ozone are initially absent in the system, a bunch of electrons of 10^{10}/cm^3 brings the system to a supercritical state, and as kinetic calculations show, a fairly large amount of thermal energy is generated during this time, as well as a sharp increase in the concentrations of atomic oxygen and ozone, up to 10^{13}/cm^3. These quantities are more than sufficient to ensure a supercritical state in the entire system, in this case in the cylinder. If the process of using thermal energy proceeds efficiently, so that the temperature of oxygen is brought close to the initial state, then the concentrations of atomic oxygen and ozone, as can be seen from Fig. 5, decrease to a minimum level. This level can be kept stationary by injecting a smaller amount of electron bunch,as compared to the initial case. Based on the fact that to obtain the required amount of electrons, incomparably less energy is spent than is obtained, it can be argued that by constantly repeating the process, we will have a new alternative source of energy. As a method of using the obtained thermal energy, for example, the Stirling engine can be proposed (Dovgyallo A.I., Nekrasova S.O., PulkinaA.Yu., 2020) to produce electricity. Pumping the thermal flow of oxygen into the primary chamber of the Stirling engine will ensure the operation of the engine. In this case, the energy spent on restoring the oxygen pressure drop due to temperature loss can be ignored, since it is incomparably smaller than the additional energy. Another approach is the method of generating electrical energy from thermal energy using an electromembrane method, which uses the fact that the flow of ions passing through membranes has a positive temperature coefficient (Martoyan G. A., Tonikyan S. G., Incheyan S. G., Karamyan G. G., 2020). This method of generating electrical energy from thermal energy is also very suitable for converting thermal energy from aqueous solutions into electrical energy.

CONCLUSION

The numerical *Value* approach (Tavadyan L.A., Martoyan G.A., 2004) based on the Hamiltonian formalization of the kinetic model of a complex reaction allows to identify critical states of chemically interacting mixtures. For example, extreme states of pressure or internal energy in the system can be used as a criterion for the critical state, when their qualitative behavior becomes very sensitive depending on the control parameters of the system. For a mixture of atomic and molecular oxygen, the existence of a critical state in the system is shown for the case of high pressures according to the proposed criterion. Controlling the electron concentrations by means of an applied electric field makes it possible to obtain the atomic oxygen concentrations necessary for ignition. The energy consumed to obtain the necessary atomic oxygen concentrations is incomparably smaller than the energy obtained by the chemical chain process in the critical state. This means that by controlling the high-pressure oxygen system with injected electrons, it is possible to turn it into an alternative renewable energy source.

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