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FOREIGN TECHNOLOGY DIVISION

EFFECT OF ULTRASONIC VIBRATIONS ON THE BURNING OF CARBON

by

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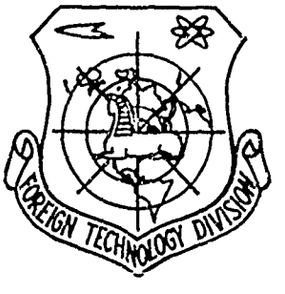

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ABSTRACT

A description is given of an experimental setup and the results of processing experimental data on the intensification of the burning of carbon through the effect of ultrasonic vibration. In the experimentation for the vibration there were used frequencies of 15, 45, and 100 kHz and energy of the sound of 3, 1.7, and 1.2 W/cm^2. Carbon rods were used for the carbon burning. They had a square section with 5-cm sides. The temperatures involved were from 600 to 1,800°C. Details are given about the roughness of the carbon sticks as their substance is being oxidized away. It is noted that about 20% of the ultrasonics is reflected from the boundary of the flame. It is found that the maxima of the burning quite clearly corresponds to the maxima for the energy of the sound. Thus in ultrasonics there burn mainly the boundaries parallel to the propagation of the wave. The peculiarity of the process can be explained by the fact that at the front and the rear boundaries nodes of displacement are formed. Orig. art. has: 5 figures and 4 references.

EFFECT OF ULTRASONIC VIBRATIONS ON THE BURNING OF CARBON

A. G. Popov

A description is given of an experimental set up and the results of processing experimental data on the intensification of the burning of carbon through the effect of ultrasonic vibration.

For the first time a method of intensifying combustion with the aid of ultrasonics was proposed in 1946 by P. N. Kubanskiy.[1] We do not know about any experimental work carried on by him in this field.

The first and, apparently, the only experimentation in this field was done in Hungary by Tarnoczy and Somhegyi [1]. They investigated the flame of illuminating gas in an ultrasonic field at a frequency of 6–17 kHz and with an energy of the sound of 0.1 W/cm^2. The effect was determined in accordance with the change in the content of carbon monoxide in the products of the combustion. The experiments did not confirm unconditionally an effect of ultrasonics on homogeneous combustion. The authors consider as the cause of this the reflection of the wave from the surface of the flame on account of the difference in the acoustic resistances at the boundary of the section. The possibility of an effect of ultrasonics on the homogeneous combustion is not brought out.

In a second series of experiments there was investigated the effect of ultrasonics on the gasification of carbon. There were used

the frequencies of 15, 45, and 100 kHz and energy of the sound of 3, 1.7, and 1.2 W/cm^2. The effect was noted also with regard to the composition of the gases. In the experiments there was obtained some change in the composition of the gases with an overall change of their output by 4-5%. The insignificance of the result the authors also explain by the reflection of the ultrasonics from the layer with the great temperature gradient. An analysis of the role of the diffusion factor in the gasification process at the temperature of 1000°C is missing in the work. With this there is exhausted the existing literary material on the question under consideration.

For the investigation of the effect of ultrasonics on the combustion of carbon in the role of radiator of elastic vibrations in the air there was used a gas-jet static generator of ultrasonics at the basis of the design of which there was put the principle of Hartmann's radiator.

The directionability of the wave motion was accomplished with the aid of projector system of Pal'me's disks and a parabolic projector. The resonator had a stabilizing pin on the principle by Ellot and Savori [2] and was designed for a frequency of 10 kHz. To the generator there was supplied an air pressure of 5-6 atm. The insulation of the air flow was attained with the aid of special screens made of cellophane or glass cloth and silk. At a distance of 80-90 mm from the resonator, measured along the axis of the parabolic projector there were located horizontally arranged rods of electrode carbon. There was used electrode graphited carbon of the following composition: moisture 0.0027-0.029%, ash content 0.19%, volatile substances 1.32-1.38%.

The rods had a square section with 5-cm sides. There were used rods with a length of the active part of 95 and 35 mm. The ends of the rods were pressed into the current carriers to which there was fed voltage from a step-down transformer of 1,200 W. The form of the transverse section and horizontal setting of the rods were chosen for the purpose of creating favorable conditions for comparing the action of the ultrasonics with the effect of natural diffusion. The use of electric current made it possible to have the object of the experiment

open for the respective orientation in the ultrasonic field. The energy of the sound was determined in accordance with the sound pressure, measurable with the aid of a piezoelectric receiver. There was used a packet of crystals of ammonium phosphate of the cut ZXt 45°. The voltage on the electrodes was measured by the high-frequency tester of the cathods voltmeter A4-M2. In computing the energy of the sound there was introduced a correction for the influence of the load resistance of the measuring circuit. The natural frequency of the vibrations of the receiver was substantially higher than the workin range of the frequencies. The computation of the effective sound pressure over the measurable stress was done in accordance with the known piezo coefficient. For the evaluation of the energy of the sound directly on the reacting surface there was taken into account the reflection of the waves from the layer with the great gradient in temperature. One should note that, contrary to stated opinion [1], the reflection of the ultrasonics is not great. Even with the ratio of the absolute temperatures of the two media, equal to 7, there is reflected about 20% of the energy of the wave motion directed at the normal to the boundary of the section.

The form and the frequency of the vibrations were recorded by the oscillograph ENO-1. It turned out that the elastic vibrations emitted by the gas generator have different frequencies in different directions. Therefore it was not possible to check the effect of the values for the amplitudes of displacement with unvarying energy of the sound. The form of the vibrations was close to the sinusoidal. On the average the ratio of the amplitude to the actual value equaled 1.6.

The temperature of the reacting surface of the carbon rod was measured by an optic pyrometer. In the experiments with a temperature lower than 800°C the measurements were made with chromel-aluminum thermocouples which were embedded by drilling in the rod. The existence of the drilling considerably raised the temperature in the given section, since the latter was decreased by about 2.5%. In all cases the temperature was measured in the center and also the edges over the length of the rod. The periodicity of the measurement was changed from one per two minutes in the experiments with low temperature to three per one minute in the experiments with high temperature. The

time of the heating of the rod to the temperature of the experiment amounted to 3.0 to 7.0% of the duration of the experiment. The latter was reckoned from the mean of the period of heating to the mean of the period of cooling within the limits of the radiation.

The carbon rods before and after the experiments were weighed. The weight of the end sections which did not take part in the combustion was determined proportionally to the part of their length in the whole length of the rod and it was computed from the original weight. The decrease in weight per unit of time was referred to the original weight of the carbon rod; it was obtained as the specific weight rate of the burning and designated as k_G^c.

The surface of the rods before and after the experiments was photographed with a magnification of X60. The original surface is characterized by a fine-grained structure and insignificant roughness. There are traces of processing and separate fine hollow places which were formed in the obtaining of the electrode carbon. In the burning in the kinetic area in the given case up to 600°C the character of the surface did not change practically.

At the temperature of 750-800°C there begins to be noted the effect of the diffusion factor, and simultaneously there is a substantial change in the character of the relief of the surface. The surface becomes sharply uneven and is covered with munute cracks. There occurs, as it were, a surface breakdown of the carbon rod. With further raising of the temperature the uneven surface is preserved.

If there were principally a burning of the high points of the unevenness this would lead to a smoothing out of the relief. One can assume the existence of some equilibrized state in which in exchange for the burnt-out roughnesses continuously new ones are formed. In any case within the limits of the height of the roughnesses, which, judging by the microphotographs, can be estimated to have a magnitude of the order of 100-200 microns, there do not exist worsening circumstances in proportion to the movement to the surface for the burning of the carbon.

With regard to the mechanism itself for the formation of the relief here one can express only an affirmation to the effect that the roughness having a genetic cause, i.e., the inequality of the burning of the separate microelements of the carbon surface, leads to the respective inequality in the surface temperatures. The latter, in turn, brings about a field of microeddies on the reacting surface, which causes an alternating intensification of the division process and unequal burning of the carbon. The peculiarity of the concentration of the oxygen at the surface creates more favorable conditions for the development of such a process. In a kinetic field with an insignificant gradient of concentration at the surface such a phenomenon cannot occur.

Independently of the mechanism of the formation of the peculiar relief of the reacting surface there is basis for doubting the unconditional correctness of using the inner geometry of the rod as the character-dimension.

The specific rates of burning by weight obtained in the experiments are given in Fig. 1. In the kinetic area, not pertinent for the investigation in question, there were few experiments made. From the temperature of 700-800°C the supplying of oxygen begins to have an influence on the overall rate of the combustion. With the rise in the temperature the processes of molar and molecular diffusion are intensified and there is an increase in the overall rate of burning. Qualitatively on the whole the picture is analogous to [3, 4]. The outer appearance of the carbon rod, burning at the average temperature of 1,285°C in the course of 8 minutes is shown in Fig. 2, a. The upper drawing is the view of rod from the side, and the lower one the view from above. With natural diffusion assuring comparatively energetic mass exchange in the lower part and on the side boundaries in these places there is noted the maximum rate of combustion. Over the length the rod burns up at a quite uniform rate.

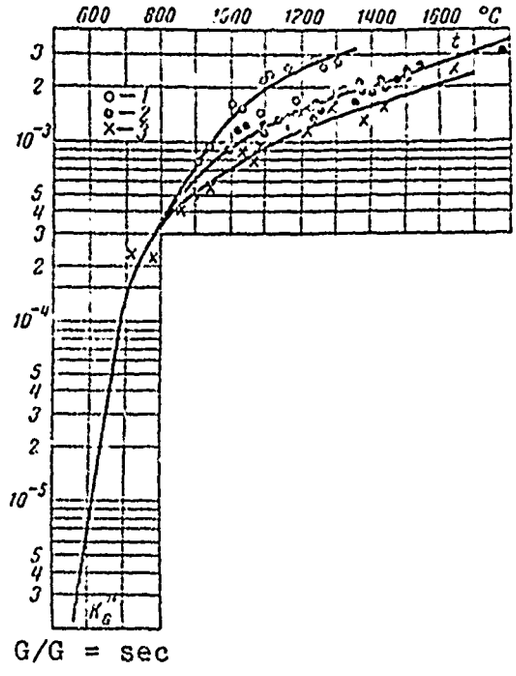

Fig. 1. Dependence of the relative rate of burning of the carbon on the temperature.

1 - average energy of the sound 0.414 W/cm^2,
2 - ditto 0.085 W/cm^2,
3 - natural diffusion.

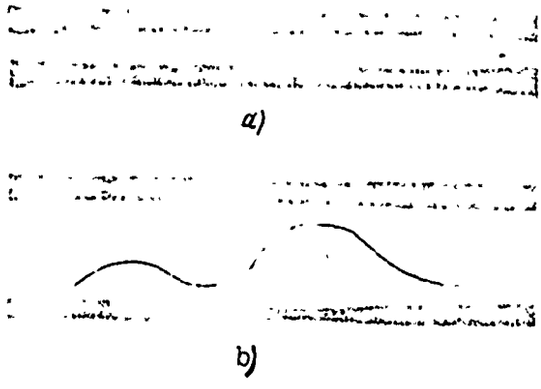

Fig. 2. Carbon rods burnt in natrual diffusion of oxydizer (a) and in ultrasonics (b).

The points which indicate the weight rate of burning of the carbon, with the use of ultrasonics (Fig. 1) are located firmly higher than those obtained under conditions of natural diffusion. The character itself of the burning also is quite different, there is shown a rod burning at the temperature of 1,476°C, and the energy of the sound is 0.455 W/cm^2. In the lower sketch the boundary of the rod lying in the plane of the drawing was oriented at right angles to the direction of the propagation of the ultrasonic vibrations. Above the same rod is shown so that the boundary lies in the plane of the drawing, the boundary in the experiment having been parallel to the direction

of the propagation of the vibrations. In the middle part of the drawing there is given a graph of the relative intensity of the ultrasonic wave in which the rod was to be found. The maxima of the burning quite clearly correspond to the maxima for the energy of the sound. Thus in ultrasonics there burn mainly the boundaries parallel to the direction of the propagation of the wave. The peculiarity of the process can be explained by the fact that in wave motion there are formed nodes of displacement at the front and rear boundaries. Therefore on these surfaces the factor of the intensification of mass exchange cannot be effected. It is clear that this did not occur in the course of the experiment. In cases of random deviations in the direction of the wave from the normal to the boundary, the standing wave broke down and the burning speeded up.

On the parallel sides the effect of the vibration rate was utilized to the fullest. The considerable roughness of the relief cannot act as an obstacle to the propagation of the vibration process, inasmuch as the length of the wave is several times as great as the dimension of the obstacles. The existence of elastic vibrations of molecules or associations of molecules of an oxidant and the products of combustion at a reacting surface with a sharply uneven relief leads to a more energetic exchange of mass and an improvement in the overall rate of heterogeneous conversion.

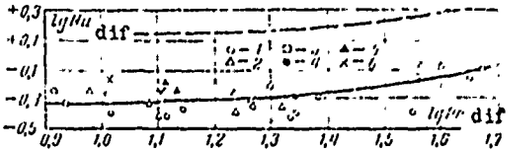

Fig. 3. Dependence of $Nu^{c}_{div} = \frac{k^{c}_{s} d}{c_0 D}$ or $Pe_{dif} = \frac{Wd}{D}$

Temperature °C: 1-1,100-1,200; 2-1,200-1,300; 3-1,300-1,400; 4-1,400-1,500; 5-1,500-1,600; 6-1,800.

In Fig. 3 there is shown the result of the processing of the experimental data in criterional form proposed by L. N. Khitrin [3], while the diffusion analog of the Peclet criterion was computed in accordance with the effective vibration rate of the wave motion. On should note that the points corresponding to the higher

temperatures lie higher.

Here, for comparison, in a broken line there is plotted the curve from [3]. The qualitative analogy is apparent. The ordinates of the two curves are not to be compared because of the effect or the form factor.

In summing up one may affirm that the action of the vibration rate of the wave motion on the process of combustion with little intensities one can in the first approximation identigy with the known influence of the rate of radiation by a steady flow. The quantitative effect at $Pe_{dif} < 30$ is described by the formula

$$Nu^{c}_{dif} = \frac{0{,}065\sqrt{Pe_{dif}}}{1-\exp(-0{,}175\sqrt{Pe_{dif}})},$$

which differs from the one proposed in [3] only in the value for the coefficients.

With $Pe_{dif} > 30$ the conformity to law, apparently, has changed. The combustion becomes more intense to a much greater degree than occurs not only in accordance with the formula given above but also in accordance with the law $Nu^{c}_{dif} \sim \sqrt{Pe_{dif}}$. However, the number of experimental points in this field is insufficient for judging definitely.

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