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THE EFFECT OF THE CARBON CONTENT ON THE DIFFUSION OF HYDROGEN IN CARBON STEELS

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- USSR -

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FOREWORD

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[Following is a translation of an article by G. I. Batalin and A. L. Balyasnyy in the Russian-language periodical *Izvestiya vysshikh uchebnykh zavedeniy. Chernaya metallurgiya* (Bulletin of the Higher Schools. Ferrous Metallurgy), No 3, 1961, pages 120-125.]

The problem of the effect of carbon content on hydrogen diffusion in steels has been examined repeatedly in the literature [1 - 4], but no final solution has been obtained up to this time.

We have investigated the effect of carbon content on the diffusion of hydrogen in carbon steels melted under plant conditions. →p.2

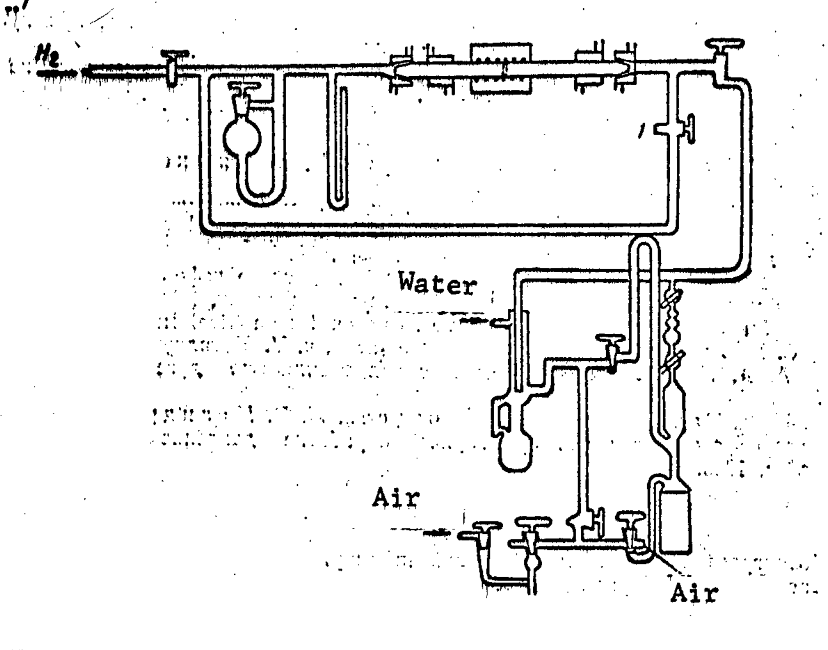

Figure 1. Diagram of the vacuum apparatus for determining the permeability of hydrogen into metals.

The penetration of hydrogen through single membranes made of 20, 30, 40, U8, and 20Kh steels was studied. A vacuum apparatus was designed for this purpose (Figure 1).

The hydrogen content was determined by means of a volumetric method, with the aid of a MacLeod-Topler pump. In order to maintain hydrogen at constant pressure in the part of the apparatus in front of the membrane, we utilized a vacuum manostat of simple design (Figure 2). When the apparatus was degassed and hydrogen was then admitted for cleaning and reducing the metal reactor, the manostat valve was opened. As soon as a certain hydrogen pressure was established, the valve was closed. As the pressure in the apparatus was reduced, the mercury in the manostat rose in the open part of the manostat due to the former pressure, with the result that the pressure in the part of the apparatus in front of the membrane remained constant. As was shown in the course of the work, the vacuum manostat operated reliably and effectively.

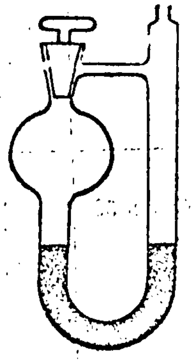

Figure 2. The vacuum manostat used in this work.

The work was done in the following sequence: At the beginning of the experiment, the apparatus was pumped out to a high vacuum, then hydrogen was admitted into the reactor which had been heated to 700 to 800° in order to rid the internal wall of the metal reactor of scale. This heating continued for an hour, with alternating pumping out and admission of new charges of hydrogen. Then the entire apparatus was degassed during heating, thus reducing the apparatus correction to a minimum value.

After the apparatus correction was reduced to a minimum, the furnace was turned off and when it was cooled down to 400°, valve 1 was opened and hydrogen was admitted to a certain pressure in the part of the apparatus in front of the membrane. The amount of hydrogen which diffused through the membrane was measured at even time intervals. When the temperature was below 400°, the diffusion process proceeded slowly, the amount of hydrogen which had diffused through the membrane exceeded the apparatus correction by only an insignificant amount, thus there was no need to conduct determinations.

Establishing the same amount of hydrogen diffusion through the membrane in equal time intervals indicated that a constant rate of diffusion of hydrogen through the membrane at a given temperature had been achieved. As soon as we had obtained two identical readings, we went on to determinations of hydrogen at a higher temperature.

It is easy to calculate the permeability of hydrogen into steel from the experimental data obtained from the penetration of hydrogen through a membrane.

As shown by Smithels, the permeability is determined by the equation

$$q = K_0 \sqrt{760}\, e^{-b/t}.$$

The equation can be represented in semilogarithmic form as

$$\log Q = C - B/T,$$

where Q is the quantity of gas in microliters which has diffused through a layer 1 square centimeter and 1 millimeter thick at normal temperature and pressure in 1 minute; $C = \log K_0 + 6.0994$;

$$B = E_0/2 \cdot 4.575;$$

K_0 is a constant which depends on the nature of the gas and the metal.

Thus, the constants C, B, and the activation energy can be found easily if we know Q and the temperature.

Table 1

Primary Experimental Data Obtained from the Penetration of Hydrogen through a Membrane P_{H_2} = = 287 mm Hg.

Type of Steel	Temperature, °C	q, ml/hr·10^2, d = 0.1 cm	Penetration
Steel 20	935	41.7	15
	875	33.2	
	825	31.5	
	800	33.2	
	730	23.9	
	655	17.8	
	575	9.5	
Steel 30	900	44.8	20
	860	38.0	
	840	31.5	
	820	36.5	
	780	31.5	
	745	26.3	
	695	21.0	
	600	13.3	
Steel 40	905	25.2	20
	840	27.8	
	790	20.7	
	715	48.0	
	650	15.2	
	580	10.1	
Steel U8	840	14.6	20
	775	11.2	
	740	10.8	
	715	10.8	
	690	7.9	
	610	4.5	
	535	2.8	
Steel 20Kh	885	35.8	20
	835	33.8	
	780	44.1	
	690	25.2	
	620	21.0	
	400	6.4	

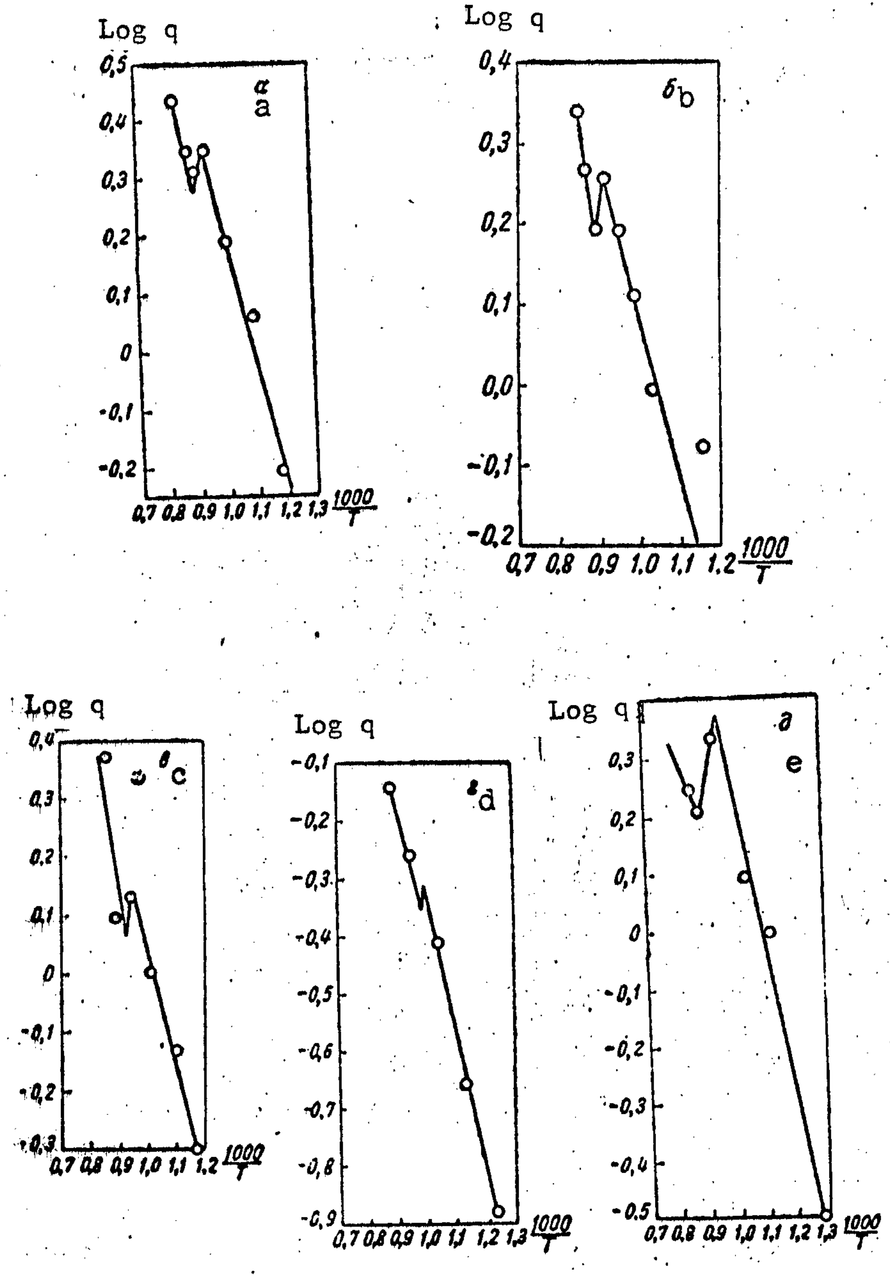

Figure 3. The permeability of hydrogen versus 1/T:
a - for steel 20; b - for steel 30; c - for steel 40;
d - for steel U8; e - for steel 20Kh.

Table 2

The Results from Calculating the Value of B for α-Fe

Grade of Steel	Value of B
20 (0.17 % C)	4,600
30 (0.27 % C)	4,600
40 (0.36 % C)	4,600
U8 (0.82 % C)	5,300
20Kh	6,600

Values of the permeability in n·ml/hr cm^2 with a membrane thickness of 0.1 cm were obtained by simple calculations (Table 1).

Figure 3 shows log q plotted versus 1/T for the steels under study. The values of B presented in Table 2 were computed by means of these curves. The values of B were computed for α-Fe; no computations were made for the γ-region due to the small amount of data.

The value of B for carbon steels remained constant up to 0.36 per cent carbon, it grew a little when the carbon content was increased to 0.82 per cent, and differed sharply from the value for steel containing chromium.

This increase in the value of B for 20 Kh steel may be ascribed exclusively to the presence of chromium as the 0.17 per cent carbon content, as shown by the data presented here, did not affect the value of B.

Figure 4 shows regions of permeability of hydrogen for α-Fe in carbon steel. Steels which have the same value of B have different coefficients C.

After computing the value of C for carbon steels, we showed the dependence of C on the carbon content in steel graphically (Figure 5). Figure 5 also shows values of C for pure iron which were determined by Smithels and Ransley [5]. The experimental points and the values of C, according to the data of Smithels and Ransley, fit a curve of the rectified hyperbola quite well. This curve makes it possible for us to determine values of C for any carbon steel of hypoeutectic composition. Thus, one can assert that the rate of diffusion drops with changes in the carbon content.

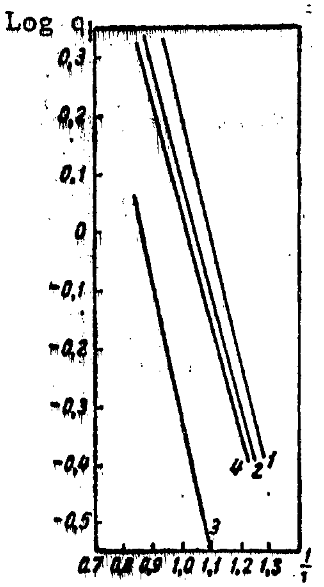

Figure 4. The permeability of H_2 vs 1/T in the α-Fe region, for the following steels:
1 - St. 20; 2 - St.30;
3 - St. 40; 4 - St. U8.

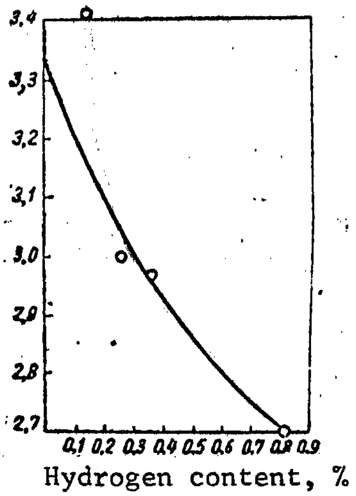

Figure 5. The coefficient C plotted as a function of the carbon content in steels.

When the results we obtained are compared with the data of other authors, one's attention is drawn to the difference in values of C. According to our data, the value of C decreases when the carbon content is increased, but according to the data of Bennek and Klotzback, it increases. Table 3 shows values of B and C for carbon steels we have computed (according to the data of Bennek and Klotzback).

Table 3

The Value of B and C

C %	soft iron	0,13	0,47	0,99
C	3,88	3,97	4,08	4,71
B	4600	4600	4800	5600

As shown in Table 3, the value of C grows with an increase in the carbon content in steel.

According to our data, the values of B run about 4,600; according to the data of Bennek and Klotzback, about 4,600; according to Chang and Bennet, 4,400; and Smithels and Ransley, 4,600 to 4,800.

Thus, the values of B as given by different authors are close to one value, since variations within limits of several per cent may be ascribed to experimental error.

Since carbon in iron forms an interstitial lattice and hydrogen is dissolved in such a lattice, it is natural to assume that when the number of interstitial carbon atoms is increased, the solution of hydrogen in the latter will be retarded and the diffusion process will likewise be retarded.

This is particularly clearly manifested in the coefficient C, which is a complicated function, as we present it, that depends not only on the nature of the gas and the metal, but also on the type of lattice, its parameters, and on impurities.

In connection with the foregoing, one must consider growth of values of C with increased carbon content as unjustified, for when the carbon content is increased, the value of B changes insignificantly and an increase in C will lead to an increase in the rate of hydrogen diffusion.

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