The processes involved in combined saturation of steels and alloys with carbon and nitrogen in a fluidized bed of carbon-graphite materials were investigated.

The mechanism of the interaction between solid carbon and atoms of nitrogen, hydrogen, and the surface of the steel was clarified by use of compound pressure and vacuum gages. The interaction of solid carbon with nitrogen and hydrogen was investigated in sealed stainless steel tubes with iron shavings subjected to nitriding and hydrogenation in a mixture with powdered carbon electrodes. Foils of steel 08kp and U9A were used to determine the saturating capacity of the compounds formed in the mixture and also above it.

Atomic hydrogen and nitrogen evolve at a high rate from the shavings with heating in vacuum, changing to molecular form, which induces a pulsating increase of pressure in the tube that disappears after a certain time. During heating of the mixture the pressure increases at a more even rate but does not disappear in the time range tested, which indicates the interaction of the nitrogen and hydrogen with carbon (Fig. 1).

It has been found [1] that saturation with carbon does not occur from the solid phase when the sample is covered. The atomic nitrogen changes to molecular form without interacting with carbon and is incapable of diffusing into the surface of steel. Saturation of the surface of foils with nitrogen and carbon, as can be seen from Table 1, indicates that the process occurs by means of the gaseous products of interaction of nitrogen and hydrogen with carbon, with formation of intermediate fast-reacting compounds (radicals of the \( \equiv \text{CH}_2, \equiv \text{CH}, -\text{C} = \text{N}, \text{C} = \text{N}^\cdot \)) that interact with the surface of the metal. Compounds with hydrogen are more stable than compounds with nitrogen, and therefore the most effective saturation with carbon and nitrogen occurs only with direct contact between solid carbon and ammonia with the surface of the metal.

This was confirmed by our studies of carbonitriding of iron in a fluidized bed of carbon-graphite materials. The investigation was conducted in a universal laboratory furnace, which is the prototype of a commercial furnace.

The kinetics and temperature dependence of combined saturation with carbon and nitrogen were investigated on samples of commercial iron and foils of steel 08kp. The surface of the samples was saturated with carbon and nitrogen in a vibrofluidized bed of charcoal. The acceleration of vibration \( \omega^2 = 789 \text{ m/sec}^2 \); the ammonia input was 28 liters/h. The dissociation of ammonia was varied in relation to temperature, amounting to 50% at 500°C and 90% at 1000°C. The samples were loaded and unloaded in a stream of argon. The supply of ammonia was shut off at this time. This made it possible to conduct the process at the desired temperature for a specific time.
Simultaneous saturation with carbon and nitrogen occurs in the first moment at all temperatures investigated (Fig. 2a). After some period of time the processes occur separately. At low temperatures saturation with nitrogen is predominant, and at high temperatures saturation with carbon. The kinetics of the change in the concentration in this and other cases follows a parabolic rule. The kinetics of saturation with carbon at low temperatures and nitrogen at high temperatures is of the extremal type.

At all holding times the temperature dependence of saturation with carbon changes by an exponential rule, with a low rate at low temperatures, and saturation with nitrogen by an extremal rule. With increasing holding times the maximum saturation with nitrogen occurs at lower temperatures. This character of the kinetics and temperature dependence of the change in the surface concentration of carbon and nitrogen can be explained by the difference in the size of the nitrogen and carbon atoms and, consequently, the difference in the diffusion mobility, as well as by the kinetics of their interaction in the metal [2] and the properties of the compounds formed.

Saturation with nitrogen is predominant in the first moments due to the small size and higher diffusion mobility of nitrogen atoms. Austenite with nitrogen is formed at some nitrogen concentration, which facilitates intensive carburizing of the steel at lower temperatures than during carburizing. The rapid increase of the nitrogen concentration at 600-750 °C is explained by the formation of ε phase, in which the solubility of nitrogen is highest.

The reduction of the nitrogen concentration in foil at temperatures above 780-790 °C is due to rapid dissociation of ammonia, which inhibits diffusion of nitrogen in austenite, i.e., the diffusion rate of nitrogen exceeds the rate of its absorption. Carbon, with high solubility in ε phase, promotes the formation of carbonitrides that are isomorphic with cementite. It is known that carbonitrides sharply reduce the rate of carbonitriding. Thus, one can expect slow growth of the diffusion layer at 780-790 °C.

**Fig. 2.** Kinetics and temperature dependence of the change in the concentration of carbon and nitrogen in foil of steel 08kp (a) and the depth of the layer on samples of commercial iron (b, c) after carbonitriding in a fluidized bed of charcoal.