

# INVESTIGATION OF AERODYNAMIC CHARACTERISTICS OF MANGANESE ORE\*

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The results of an investigation of the aerodynamic characteristics of manganese ore, ready for delivery from the pit and sorted out in fractions, are presented for the humidity range 1.3 to 8.5%. The formulas for computing the pressure drop in the bed, the velocity of start of fluidization, and the velocity of entrainment of the particles are also given.

In designing apparatuses and processes based on the interaction of a gaseous flux with the solid phase (boiling-layer apparatus, pneumatic transport, etc.) a knowledge of the aerodynamic characteristics of the material is necessary.

In the process of preparing the sinter cakes the manganese ore is subjected to drying in a boiling layer and to pneumatic transport.

The aerodynamic characteristics of the manganese ore were investigated mainly for the purpose of the subsequent development of a continuously operating drying apparatus, but the results obtained here can be useful also in other cases in computing the interaction of a gas flux with the layer and individual particles.

During the investigation the characteristics of the purged layer were determined at different stages of its drying, and also of the individual particles during their interaction with the gas flux: the aerodynamic

\* Crushed pyrolusite  $MnO_2$  of Chiaturskii mine.

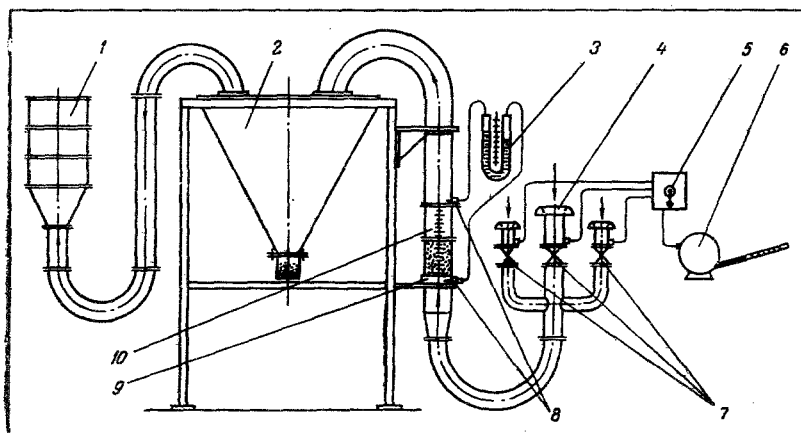


Fig. 1. Schematic diagram of the experimental equipment: 1) air-blowing station, 2) precipitator bunker, 3) micromanometer, 4) measuring spherical collector, 5) switch, 6) micromanometer, 7) valves, 8) pressure gauges, 9) gas-distributor grate, 10) reactor.

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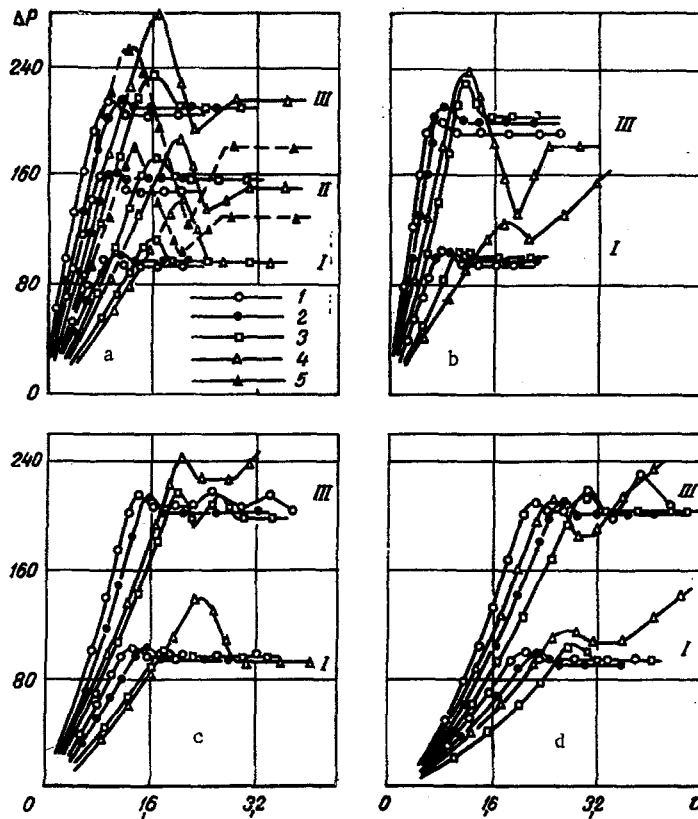


Fig. 2. Aerodynamic characteristics of a layer of manganese ore with different humidities for polydisperse composition and for individual fractions: a) polydisperse material 0-5 mm: 1)  $W=1.3\%$ , 2)  $5.0$ , 3)  $6.5$ , 4)  $8.3$ , 5)  $7.2\%$ ; b) fraction  $d_e=1.41$  mm: 1)  $W=1.3\%$ , 2)  $4.2$ ; 3)  $5.85$ , 4)  $W=7.5\%$ ; c) fraction  $d_e=4.24$  mm: 1)  $W=1.3\%$ , 2)  $3.9$ , 3)  $5.2$ , 4)  $W=6.2\%$ ; d) fraction  $d_e=4.24$  mm: 1)  $W=1.3\%$ , 2)  $4.0$ , 3)  $5.3$ , 4)  $W=6.1\%$ ; I)  $G/F_a=116$   $\text{kg/m}^2$ ,  $H_0=53$  mm; II)  $174$  and  $77$ ; III)  $232$   $\text{kg/m}^2$  and  $105$  mm.  $\Delta P$ ,  $\text{daN/m}^2$ ;  $v$ ,  $\text{m/sec}$ .

resistance of the layer  $\Delta P$ , the velocity of start of fluidization  $w'_{cr}$ , expansion of the layer at start of fluidization and during the entire period of existence of the fluidized layer, the nature and peculiarities of the fluidized layer, and the velocity of removal (entrainment) of the particles  $w_{en}$ .

The investigations were conducted with manganese ore ready for delivery from the pits of the mining industry. The ore is a polydisperse material with range of size of the particles from 0 to 5 mm and initial humidity of 1.3 to 8.5%. The individual fractions of this ore have the following characteristics:  $d_1=0.5-1.0$  mm,  $d_{e1}=0.71$  mm,  $d_2=1.0-2.0$  mm,  $d_{e2}=1.41$  mm,  $d_3=2.0-2.5$  mm,  $d_{e3}=2.24$  mm,  $d_4=3.0-3.5$  mm,  $d_{e4}=3.24$  mm,  $d_5=4.0-4.5$  mm, and  $d_{e5}=4.24$  mm in the same range of humidity. The investigations were carried out on the equipment whose schematic diagram is shown in Fig. 1. A weighed amount of the investigated material was placed on the gas-distributor grate 9 in reactor 10 and was blown through by air stream from the blowing station 1. The flow rate of air was regulated by valves 7 and controlled by the inlet spherical collectors 4 having different nominal ducts; this made it possible to vary and measure the rate of filtration in the range from zero to the velocity of entrainment of the particles from the reactor. The particles removed from the reactor were deposited in chamber 2. Switch 5 connected the measuring micromanometer 6 to one or the other collector. The pressure drop in the layer was regulated by micromanometer 3. The pressure drop was measured by the direct method using needle gauges 8 mounted above the gas-distributor grate and above the layer. The initial height of the layer filling and its expansion during the experiment were measured from the graduation of the reactor. The nature of the fluidized layer was estimated visually.

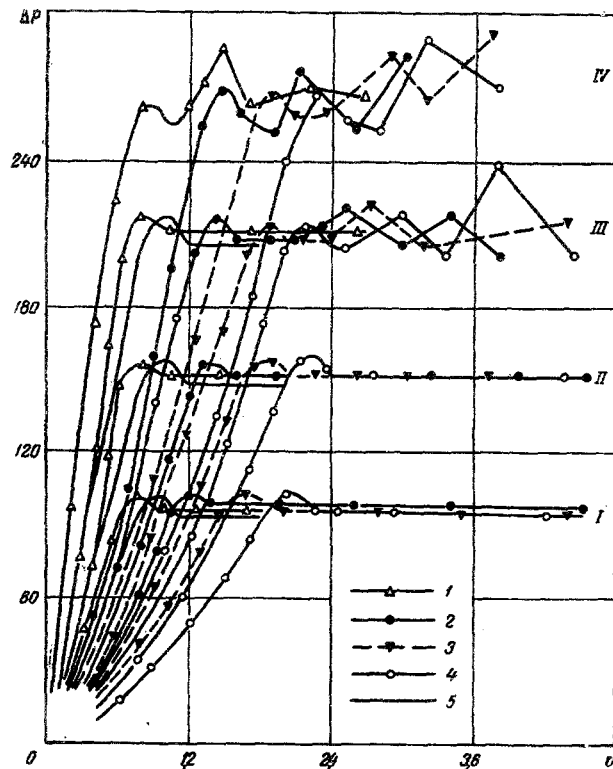


Fig. 3. Aerodynamic characteristics of a layer of manganese ore for equilibrium humidity of 1.3%: 1) fraction  $d_e=1.41$  mm, 2) 2.24, 3) 3.24, 4)  $d_e=4.24$  mm, 5) polydisperse material 0-5 mm; I,  $G/F_a = 116$  kg/m<sup>2</sup>,  $H_0=53$  mm, II, 174 and 77, III, 232 and 107, IV,  $G/F_a = 290$  kg/m<sup>2</sup> and  $H_0=135$  mm,  $v$ , m/sec.

The results of the experimental investigation are presented in Figs. 2 and 3 for a polydisperse layer and for some fractions. An analysis of these results shows that the rate of start of fluidization depends on the humidity of the ore (Fig. 4). An increase in the humidity of the manganese ore leads to an increase of the critical velocity of start of fluidization both for the polydisperse material and individual fractions. For a velocity of start of fluidization  $w'_{cr}$  for dry ore (humidity 1.3%) equal to 1.0-2.4 m/sec an increase of the humidity to 5% results in an increase of  $w'_{cr}$  by 0.05-0.08 m/sec per 1% humidity; on increasing the humidity from 5 to 8% the increase in  $w'_{cr}$  is already 0.2-0.35 m/sec per 1% humidity (the larger values pertain to smaller fractions and the smaller, to larger fractions). The reasons for the increase of  $w'_{cr}$  with the humidity are the following: 1) formation of an aggregate of particles resulting in an increase of the mean size; this phenomenon is especially typical of the polydisperse material; 2) formation of stable channels, which appears especially in the humidity range 5-8%, since there occurs a change of the initial structure of the layer, a decrease of its filled mass from  $2.2 \cdot 10^3$  at 1.3% humidity to  $1.77 \cdot 10^3$  at 7.3% humidity. For the humidity of the material equal to 8% or more the layer ceases to be friable and goes over into a viscous state.

The velocity of start of fluidization for a polydisperse material with the same humidity changes depending on the percentage content of large and small fractions in the layer, but it always remains lower than the velocity of fluidization of the largest fraction in this layer. For a fixed humidity this rate is almost independent of the height of the layer of the material in the reactor.

The resistance of the layer of a given initial humidity and height is almost independent of the average size of the fractions. At the instant of its transition into the fluidized state the resistance of the layer exceeds the resistance of the fluidized layer and the greater the humidity and polydispersiveness of the layer, the larger is this exceedance; this is explained by the necessity of overcoming the force of adhesion of the particles.

The expansion of the layer at the instant of transition into the fluidized state is 15-20% for the monodisperse layer and 25-40% for the polydisperse layer. Subsequently, with the increase of the rate of

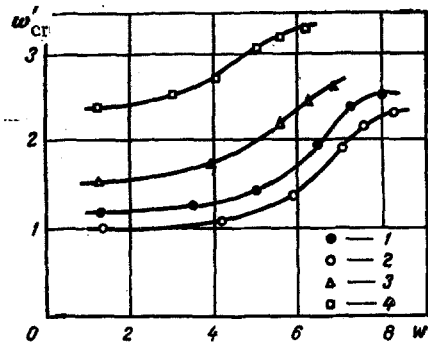


Fig. 4. Rate of start of fluidization as a function of the humidity of the manganese ore: 1) polydispersive material 0-5 mm, 2) fraction  $d_e = 1.41$  mm, 3) 2.24, 4) 4.24 mm.  $W$ , %.

filtration of the gas flux to  $2 w'_{cr}$ , the height of the boiling layer of the polydispersive material increases by a factor of 2-2.5 compared to the initial height  $H_0$ .

The stable regime of boiling of manganese ore occurs for the height of the layer equal to 1.2-1.25 times the diameter of the apparatus and for humidity up to 6.5-7.0%. An increase of the height of the layer or of the humidity up to 7% results in the formation of channels and pistons. In order to avoid such a regime it is necessary to increase the rate of filtration of the gas considerably, which is inadmissible because of appreciable removal of small fractions from the layer.

The range of existence of the fluidized (boiling) layer for fractions of different equivalent diameter lies within the range of values of the ratio of the entrainment velocity  $w_{en}$  to the velocity of fluidization  $w'_{cr}$ ,

$$\frac{w_{en}}{w'_{cr}} = 7.5-14.$$

The analysis of the experimental results showed that the resistance of the boiling layer can be calculated from the well-known formula [1, 4, 5]

$$\Delta P = (1 - \epsilon_0)(\gamma_s - \gamma_g)H_0, \text{ daN/m}^2. \quad (1)$$

The dependence of the resistance of the boiling layer on the load at the gas-distributor grate is linear and can be determined from the equation

$$\Delta P = 0.973 \frac{G}{F_a} - 15.4, \text{ daN/m}^2. \quad (1')$$

For overcoming the force of adhesion during the transition of the layer to the fluidized state the blowing equipment must have a pressure reserve of 25% above the value computed from formulas (1) and (1').

The experimental values of the critical velocity of start of fluidization at humidities of the ore up to 3.5% are in good agreement with the values computed from the formula [1, 5]

$$Re'_{cr} = \frac{Ar \cdot \epsilon^{4.75}}{18 + 0.61 \sqrt{\epsilon^{4.75} \cdot Ar}}. \quad (2)$$

With the increase of the humidity of the ore above 3.5% the computed values of the rate must be increased in accordance with the recommendations made earlier. Here

$$Re'_{cr} = \frac{w'_{cr} d_e}{\nu}$$

and

$$d_e = \sqrt{d_1 d_2}.$$

For  $\epsilon = 1.0$  formula (2) gives a value of the velocity of entrainment of the particles, that is, the upper limit of existence of the boiling layer:

$$Re_{en} = \frac{Ar}{18 + 0.61 \sqrt{Ar}}. \quad (2')$$

The rate of complete fluidization for the polydispersive layer of manganese ore can be determined from formula (2) or from the formula

$$\text{Re}_T = 0.049 [(1 - \varepsilon_0) \text{Ar}]^{0.8} (D_{me})^{0.48} \left( \frac{\gamma_g}{\gamma_s} \right)^{0.2}, \quad (3)$$

where

$$D_{me} = \frac{d_{max}}{d_e}; \quad d_e = \frac{1}{\sum \frac{\Delta i}{d_i}}.$$

The parameters computed from formulas (1)-(3) diverge from the experimental values by 6-10%; this divergence is totally admissible for practical computations.

#### NOTATION

$\Delta P$ , layer resistance, daN/m<sup>2</sup> (mm of water column);  $w'_{cr}$ , velocity of onset of fluidization, m/sec;  $w_{en}$ , drift velocity (entrainment) of particles, m/sec;  $d$ , particle diameter, m;  $d_e$ , equivalent diameter of particles, m;  $\varepsilon_0$ ,  $\varepsilon$ , layer porosities of fixed and fluidized layers respectively;  $\gamma_s$ , specific weight of solid particles, kg/m<sup>3</sup>;  $\gamma_g$ , specific weight of gas phase, kg/m<sup>3</sup>;  $H_0$ , initial height of the layer, m;  $G$ , layer mass on gas-distributing grate, kg;  $F_a$ , area of gas distributing grate, m<sup>2</sup>;  $\text{Re}'_{cr}$ ,  $\text{Re}_T$ ,  $\text{Re}_{en}$ , Reynolds numbers corresponding to layer transition to fluidized state, total fluidization, and particle entrainment;  $\text{Ar} = (gd^3/\nu^2) \cdot [(\gamma_s - \gamma_g)/\gamma_g]$ , Archimedes number;  $g$ , acceleration due to gravity;  $\Delta i$ , particle fraction in mixture over mass size  $d_i$ , calculated as mean harmonic size of cells of adjacent sieves;  $D_{me}$ , modified polydispersion number;  $d_{max}$ , maximum size of particles, m.

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