# The mathematical model of ore particles and conveyor belt interacting process

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Abstract
Objective: The establishment of regularities of ore particles and conveyor belt interacting with the object of the adhesive properties determination of high-absorbency finely-divided systems influencing the intensity of dust formation during conveyor operation.

Result: The capillary composite adhesive force intensity depends on surface of liquid tension, the ratio of the liquid layer thickness to the particle radius and the curvature of meniscus, which was formed after particle wetting with liquid.
Scientific novelty: The mathematical model of ore particles and conveyor belt interacting process was developed considering adhesion and autohesion forces.
Practical relevance: The ways of creation of methods and means for air dust content in mine opening reduction are outlined according to researches results.
Key words: CONVEYOR BELT, ADHESION FORCES, DUST CONTENT, ATMOSPHERE, MINE OPENING, ORE.

The earlier studies of granular materials physical properties [1] showed that the ore adhesion usually depends on molecular moisture capacity and water affinity.

The average maximum molecular moisture capacity for manganese ore mined at the mine No 9-10 is W = 22.53, i.e. it is quite high and caused by such components of the ore as clay, earthy oxides of manganese and others. In the development of adhesion forces of clayey materials, which are finely-divided systems, the major role belongs to capillary forces, which net action is caused by water meniscus surface tension forces.

When capillary forces reach a certain size, in course of time the clayey material particles and belt surface approach each other spontaneously, as the result the molecular linkage between them is developed. On removing of the fluid from the boundary layer due to the possible evaporation and its suction by less wet overlying clay layers, the clay adhesion to the belt increases. The moisture in the adhesive material and belt contact area causes the cohesive force tangentially directed to the surface of contact and adhesion forces normally directed to the surface of the belt.
The manganese ore water affinity is quite low (65.2%), probably due to mineralogical and fractional composition of dust and short wetting time, which is not enough for clay particles swelling.

The natural moisture content of mined manganese ore is 27% on average, which is higher than the maximum molecular moisture capacity. We can assume that there is liquid layer between the transported ore and the conveyor belt surface. The quantitative estimation of manganese ore particles and conveyor belt surface interacting when liquid layer sticking to the belt is important for the correct selection of reducing methods and means of ore adhesion to the belt.

Having regard to the above, the calculation of single particle adhesion forces on the conveyor belt is of great importance.

Let us consider the interaction between a spherical particle of radius R and a flat surface of the conveyor belt when liquid layer of thickness h sticking to it. The particle wetting angles will be considered as known (Fig. 1).

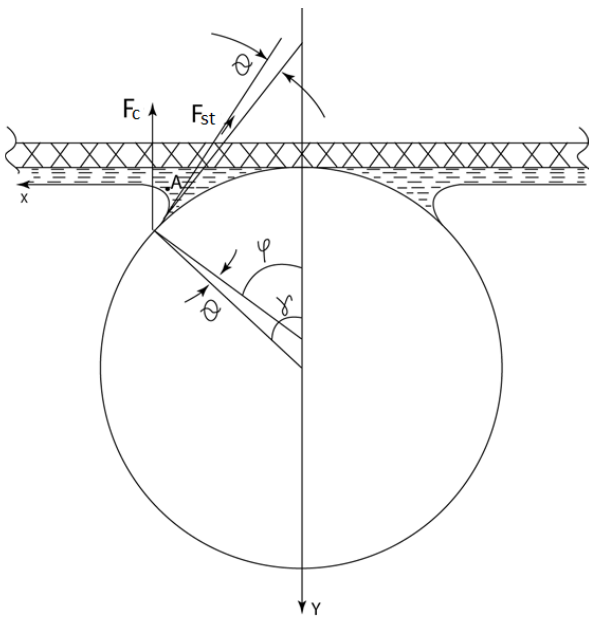


**Figure 1.** Calculation of the capillary component of the adhesion force

Let us define the shape of the meridional curve (the curve, which revolution forms the curved surface of the liquid-gas). The liquid surface of the belt is taken as axis x and the vertical line passing through the center of a spherical particle is taken as axis y. Let x and y indicate the current coordinates of the point on the meridian curve.

The pressure P inside the liquid at the point A is

$$P = P_0 - \rho g y \quad (1)$$

where $P_0$ – atmosphere pressure, Pa

$\rho$ – liquid density, kg/m[3]

The same pressure can be expressed by the Laplace formula

$$P = P_0 - \sigma k \quad (2)$$

where $\sigma$ - liquid tension, n/m

$k$ – absolute value of liquid surface curvature at point A, 1/m

Consequently:

$$\rho g y = P_0 - P = \sigma k \quad (3)$$

Considering that the radius of the particle is much greater than the layer thickness therefore we neglect the pressure change throughout the height of the fluid under the influence of gravitational forces. In this case

$$P_0 - P = \sigma k = const \quad (4)$$

The absolute value of the surface curvature at the point A is

$$k = \frac{1}{R_1} + \frac{1}{R_2} \quad (5)$$

where $R_1$ - the curvature radius of the meridional curve in the plane xy, m;

$R_2$ - the curvature radius of the normal section, which is perpendicular to the meridional curve, m.

It is known that

$$\frac{1}{R_1} = -\frac{y''}{(1+y'^2)^{1,5}} \quad (6)$$

(the prime denotes the axis x differentiation). The radius of curvature R is the negative value.

The radius of curvature $R_2$ is easily determined by Meusnier theorem, which is known from differential geometry. According to this theorem

$$x = R_2 \cos\alpha \quad (7)$$

where $\alpha$ - the angle between the plane of normal section and the axis x.

Substituting the value cosα in the formula (7), we obtain

$$R_2 = \frac{x(1+y'^2)^{0,5}}{y'} \quad (8)$$

Thus, the differential equation, which determines the shape of the meridional curve, takes the form

$$\frac{y'}{(1+y'^2)^{0,5}} - \frac{y''}{(1+y'^2)^{1,5}} = const = 2H \quad (9)$$

Transforming the formula (9) to the form

$$\frac{d}{dx}\left(\frac{xy'}{(1+y'^2)^{0,5}}\right) = 2Hx \quad (10)$$

Integrating the equation (10), we obtain

$$\frac{xy'}{(1+y'^2)^{0,5}} = Hx^2 + B \quad (11)$$

where B - integration constant.

The formula (11) after simple transformations takes the form

$$\frac{dy}{dx} = \frac{Hx^2+B}{\sqrt{x^2-(Hx^2+B)^2}} \quad (12)$$

from which

$$y = \int \frac{Hx^2+B}{\sqrt{x^2(Hx^2+B)}} dx + c \quad (13)$$

where c – the second integration constant.

The adhesive force capillary component acting on the particle is

$$F_c = F_{st} \sin\varphi \quad (14)$$

where $F_{st}$ - surface tension force acting on the wetting perimeter and is directed at a tangent to meniscus, N;

φ – the angle between the tangent to meniscus at the highest point of the liquid rise and the perpendicular to axis x, rad.

$$F_{st} = 2\pi\sigma x \quad (15)$$

where x - ordinate of the point of the highest liquid rise

$$x = R \sin\gamma \quad (16)$$

where $\gamma$ - the angle between the radius drawn to the point of the highest liquid rise and the radius drawn to the point of particle contact with the belt surface.

From the drawing it follows

$$\cos\gamma = \frac{R-h-y}{R} = 1 - \frac{h}{R} - \frac{y}{R} \quad (17)$$

where y - ordinate of the point of the highest liquid rise.

Considering that y is significantly less than R, from (17) we obtain

$$\cos\gamma = 1 - \frac{h}{R} \quad (18)$$

from which

$$\sin\gamma = \sqrt{\frac{2h}{R}\frac{h^2}{R^2}} \quad (19)$$

Using the ratio known from the trigonometry

$$\sin\varphi = \frac{tg\varphi}{\sqrt{1+tg^2\varphi}} \quad (20)$$

and considering the formula (12), we obtain

$$\sin\varphi = \frac{y'}{\sqrt{1+y'^2}} = \frac{Hx^2+B}{x}$$

(21)

Substituting the equations (15) and (21) into (14) considering the equations (16) and (19), we obtain

$$F_c = 2\pi\sigma R^2 H\left(\frac{2h}{R} - \frac{h^2}{R^2}\right) + 2\pi\sigma B \quad (22)$$

If h = 0, $F_c = 0$, then B = 0 and the formula (21) takes the form

$$F_c = 2\pi\sigma R^2 H(\frac{2h}{R} - \frac{h^2}{R^2}) \quad (23)$$

The particle will be kept on the surface if

$$F_c \geq P$$

where $P = \frac{4}{3}\pi\rho R^3$ – gravity force acting on the particle, N;

$\rho$ – liquid density, kg/m3.

Dividing both sides of (22) into the force of gravity acting on the particle, we obtain

$$\frac{F_c}{P} = \frac{3}{2} \times \frac{\sigma}{\rho g} \times \frac{H}{R}(\frac{2h}{R} - \frac{h^2}{R^2}) \quad (24)$$

Thus, the adhesion force capillary component magnitude depends on liquid surface tension, the ration of the liquid layer thickness to the particle radius and the curvature of meniscus formed by the particle wetting with liquid.

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